

Table 3. Summary of Peak Annual Releases From White Oak Dam for the Eight Key Radionuclides (1944–1991)

<i>Radionuclide</i>	<i>Peak Annual Releases (curies)</i>			<i>Number of Years at 10% of Peak Release or More</i>
	<i>Lower Bound</i>	<i>Central Estimate</i>	<i>Upper Bound</i>	
Cesium 137	50	200	510	14
Ruthenium 106	1,600	2,100	2,700	5
Strontium 90	68	190	390	18
Cobalt 60	64	85	110	15
Cerium 144	70	94	120	13
Zirconium 95	72	210	440	9
Niobium 95	17	200	520	10
Iodine 131	10	68	190	10

Source: ChemRisk 2000

Annual estimates were based on data in log books, interviews with knowledgeable parties, and laboratory documents.

II.C. Remedial and Regulatory History

As a result of several on-site processes that produced nonradioactive and radioactive wastes, on November 21, 1989, EPA listed the ORR on the final National Priorities List (NPL) (EUWG 1998; USDOE 2001a; USEPA 2002a). The DOE is performing remediation activities at the reservation under a Federal Facility Agreement (FFA), which is an interagency agreement between the DOE, EPA, and TDEC. The EPA and TDEC, along with the public, help DOE select the details for remedial actions at the ORR (USDOE 2003a). These parties work collaboratively to ensure that adequate remediation activities are used, and to ensure that hazardous waste related to previous and current ORR activities is completely studied and appropriate remedial action is taken (USDOE 1996b, 2003a). DOE is conducting its investigations of the ORR under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), a program that requires an FFA be established for all NPL sites owned by the federal government (EUWG 1998; USEPA 2002b). In addition, DOE is incorporating response procedures designated by CERCLA, with mandatory actions from the Resource Conservation and Recovery Act (RCRA) (USEPA 2002b). See Figure 5 for a time line of major processes, environmental data, and public health activities associated with the X-10 site.

The Federal Facility Agreement was implemented at the ORR on January 1, 1992. This is a legally binding agreement used to establish schedules, procedures, and documentation for remedial activities at the ORR (EUWG 1998). The Federal Facility Agreement is available online at <http://www.bechteljacobs.com/pdf/ffa/ffa.pdf>.

Radioactive waste material, such as Cs 137 and Sr 90, is present in old waste sites at the ORR. These waste sites constitute 5% to 10% of the reservation. Releases from these waste sites, as well as leaching caused by abundant rainfall and high water tables, have contributed to the radionuclide contamination of surface water, groundwater, soil, and sediments at the ORR (EUWG 1998). According to DOE, waste sites located in the Melton Valley Watershed "...are the primary contributors to off-site spread of contaminants" from the ORR and White Oak Creek flows through or past these areas (USDOE 2002b).

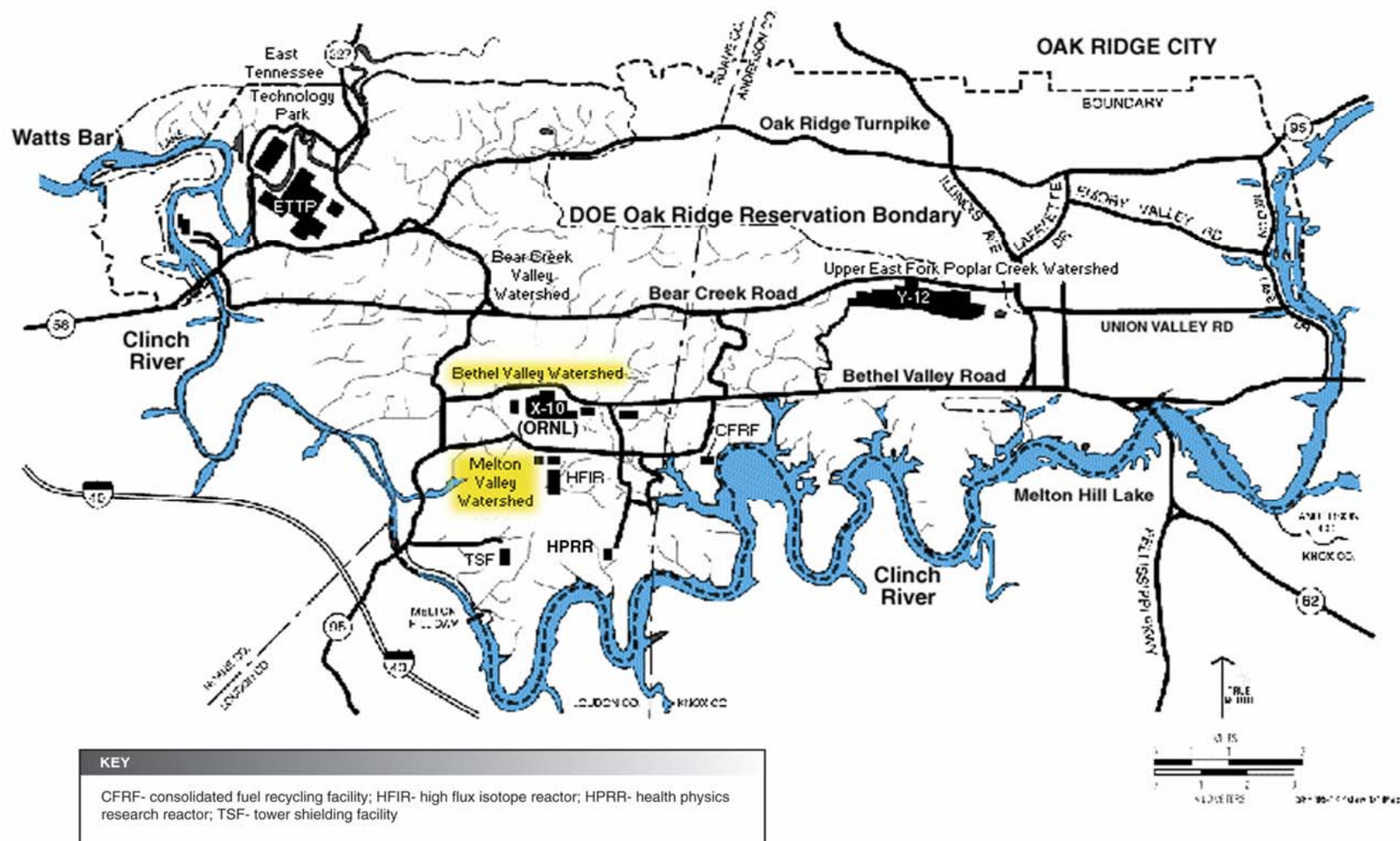
In 1986, DOE began remedial actions at the ORR under a RCRA permit. Since that time, DOE has started about 50 response activities under the FFA that address waste disposal and contamination issues on the reservation (USEPA 2002a). To facilitate the investigation and remediation of contamination related to the reservation, the contaminated areas on the ORR were separated into five large tracts of land that are typically associated with the major hydrologic watersheds (EUWG 1998). More specifically, the contaminated areas associated with X-10 are located in the Bethel Valley Watershed and the Melton Valley Watershed (USDOE 2001b). Please refer to Figure 9 for the locations of these two watersheds.

Although not current public health concerns, some of these former waste disposal sites are nonetheless subject to remediation. DOE is remediating these sites to ensure long-term safety and to prevent off-site releases. More information on DOE's environmental management program can be obtained at <http://www.oakridge.doe.gov/External/Default.aspx?tabid=42>.

II.C.1. Bethel Valley Watershed

The major operations at X-10 take place within the Bethel Valley Watershed. The main plant, key research facilities, primary administrative offices, as well as various forms of waste sites, are situated in Bethel Valley. Over the past 60 years, X-10 releases have contaminated the Bethel Valley Watershed. Mobile contaminants primarily leave the Bethel Valley Watershed via White Oak Creek. These contaminants travel from the Bethel Valley Watershed to the Melton Valley Watershed, where further contaminants enter White Oak Creek. Then, the contaminants that have been discharged to White Oak Creek are released over White Oak Dam and into the Clinch River (USDOE 2001b).

Figure 9. Map of the Bethel Valley Watershed and the Melton Valley Watershed



Source: Lockheed Martin Energy Systems, Inc. 1998

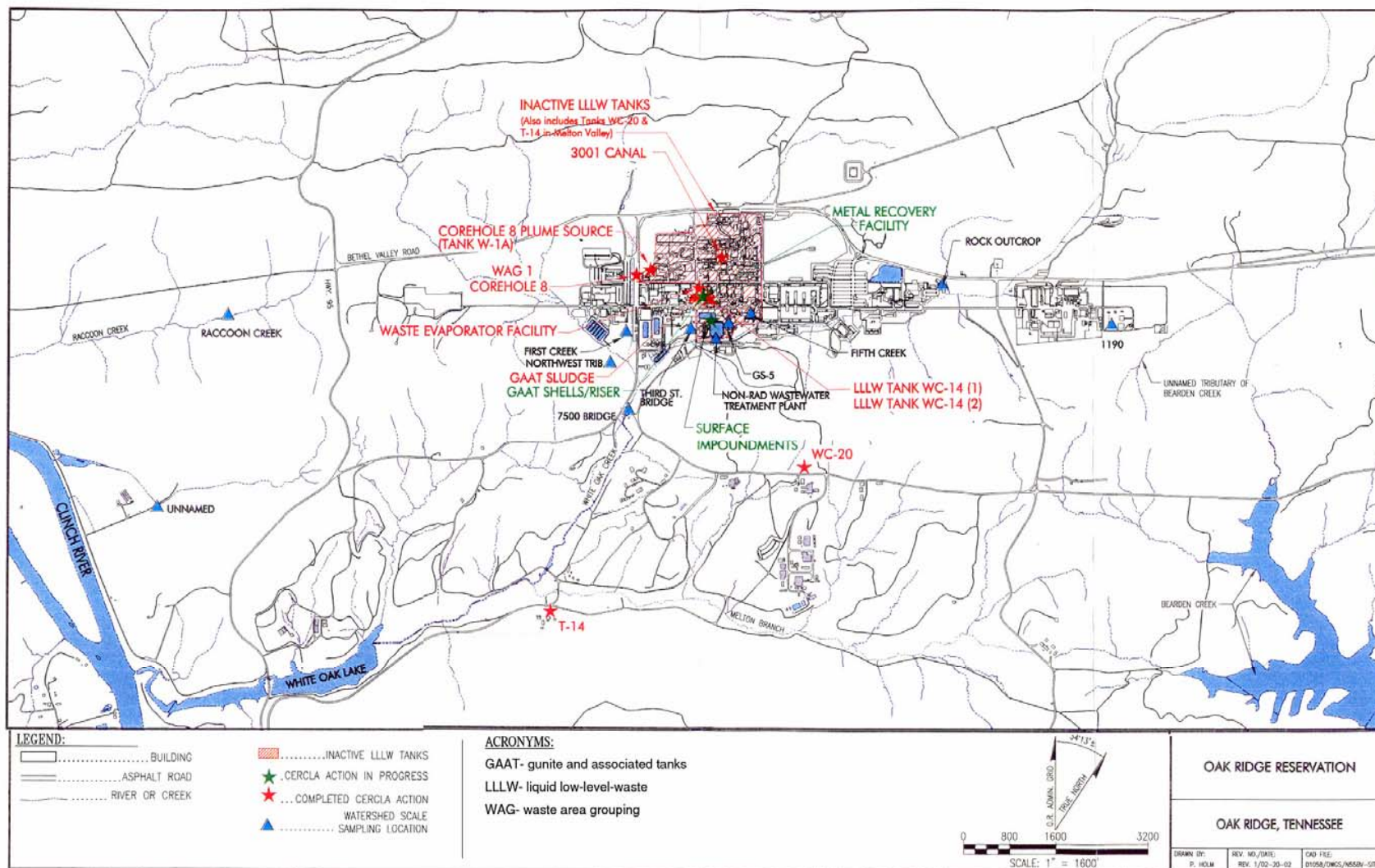
Many remedial activities have been conducted in Bethel Valley to protect human health and the environment in the present and future. These actions, which comply with federal and state requirements, have removed the most contaminated materials (including source and leaching materials) and reduced the amount of contaminants in Bethel Valley. Main remedial activities conducted in Bethel Valley associated with X-10 operations have included 1) groundwater treatment and extraction at the Corehole 8 Plume, 2) sludge and liquid waste removal at the Gunit and Associated Tanks (GAAT), 3) liquid and solid waste removal and treatment at the inactive liquid low-level waste tanks, and 4) contaminated sediment removal from the surface impoundments operable unit (SAIC 2002, 2004; USDOE 2001c). In addition, in May 2002 a Record of Decision (ROD) was signed to address several interim remedial actions in Bethel Valley. As of the 2004 fiscal year, ROD-initiated activities—including a groundwater study—had begun (SAIC 2005). Please see Figure 10 for a map of Bethel Valley that includes these areas. The main remedial activities conducted in Bethel Valley are detailed further in Appendix B.

II.C.2. Melton Valley Watershed

X-10 disposed of its radioactive wastes (liquid and solid) in Melton Valley, and also operated its experimental facilities within this watershed (USDOE 2002a, 2002b). Discharges from Melton Valley's waste areas have produced secondary contamination sources that include sediment, groundwater, and soil contamination. Furthermore, contaminants discharged from Melton Valley travel off the reservation through surface water and flow into the Clinch River (SAIC 2002). As a result, the waste sites in the Melton Valley Watershed "...are the primary contributors to off-site spread of contaminants" from the ORR (USDOE 2002b).

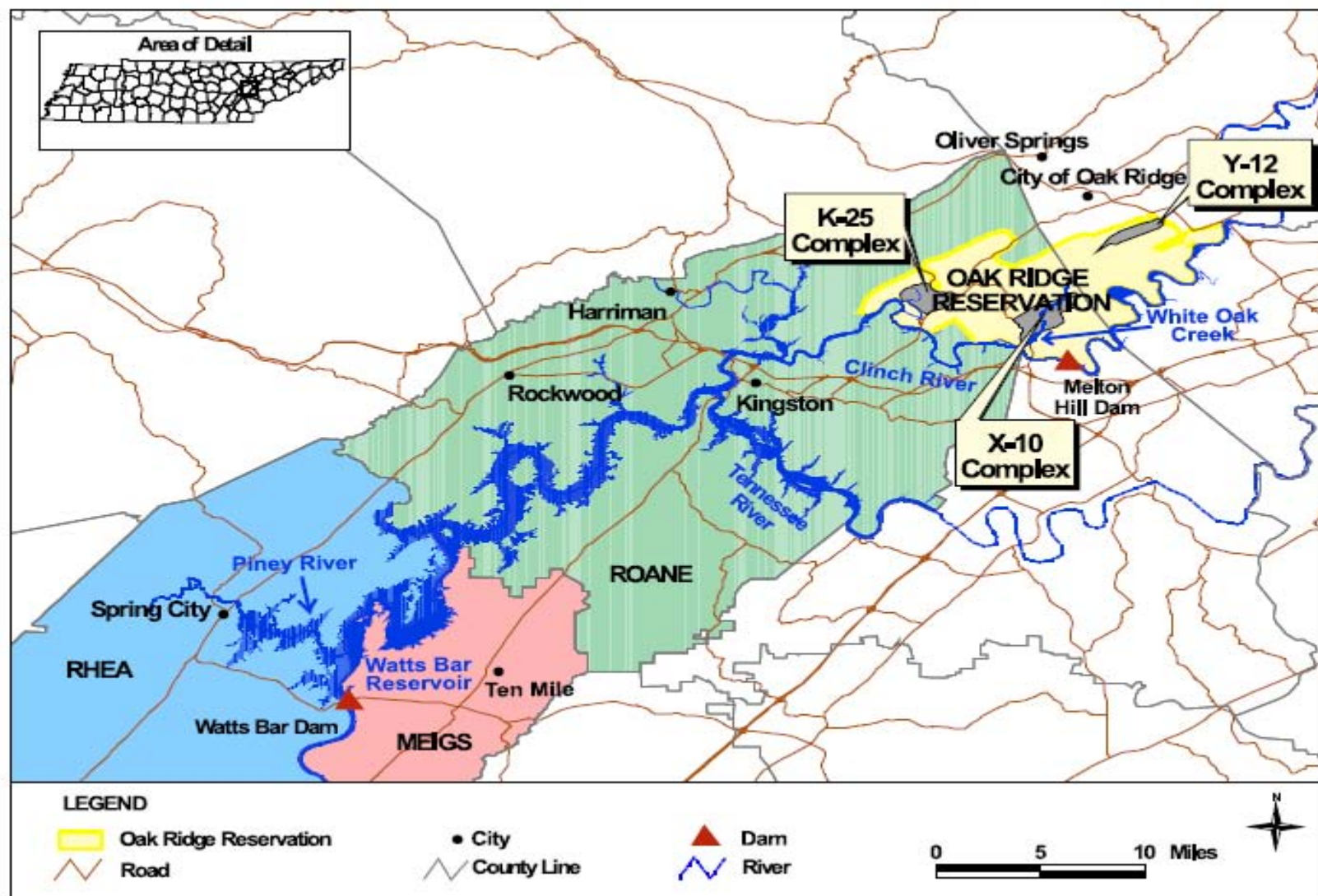
Many remedial activities, which comply with federal and state requirements, have been conducted in Melton Valley. These actions—undertaken to protect human health and the environment in the present and future—have removed the most contaminated materials and reduced the amount of contaminants in Melton Valley. Main remedial activities related to X-10 operations and the White Oak Creek study area (see Figure 11) have included 1) removing contaminated soil and restricting access to the Cesium Plots Research Facility, 2) building a

Figure 10. Map of the Major Remedial Activities in Bethel Valley



Source: SAIC 2002

Figure 11. Map of the White Oak Creek Study Area



sediment retention structure at the mouth of White Oak Creek to reduce off-site movement of sediments to the Watts Bar Reservoir and the Clinch River, 3) reducing releases of strontium 90 into White Oak Creek from waste area grouping (WAG) 4 trenches, 4) installing a groundwater treatment unit at WAG 5 to prevent strontium 90 from entering Melton Branch, and 5) injecting radioactive waste and grout below ground and removing liquid low-level waste (LLW) underground storage tanks (USTs) from the Old Hydrofracture Facility (OHF) (SAIC 2002; USDOE 2002c; USEPA 2002a). A ROD signed in September 2000 focused on remedial activities to prevent contaminant releases into surface waters and groundwater in Melton Valley (SAIC 2002, 2004). Please see Figure 12 for a map of Melton Valley that includes these areas. The main remedial activities conducted in Melton Valley are further detailed in Appendix B.

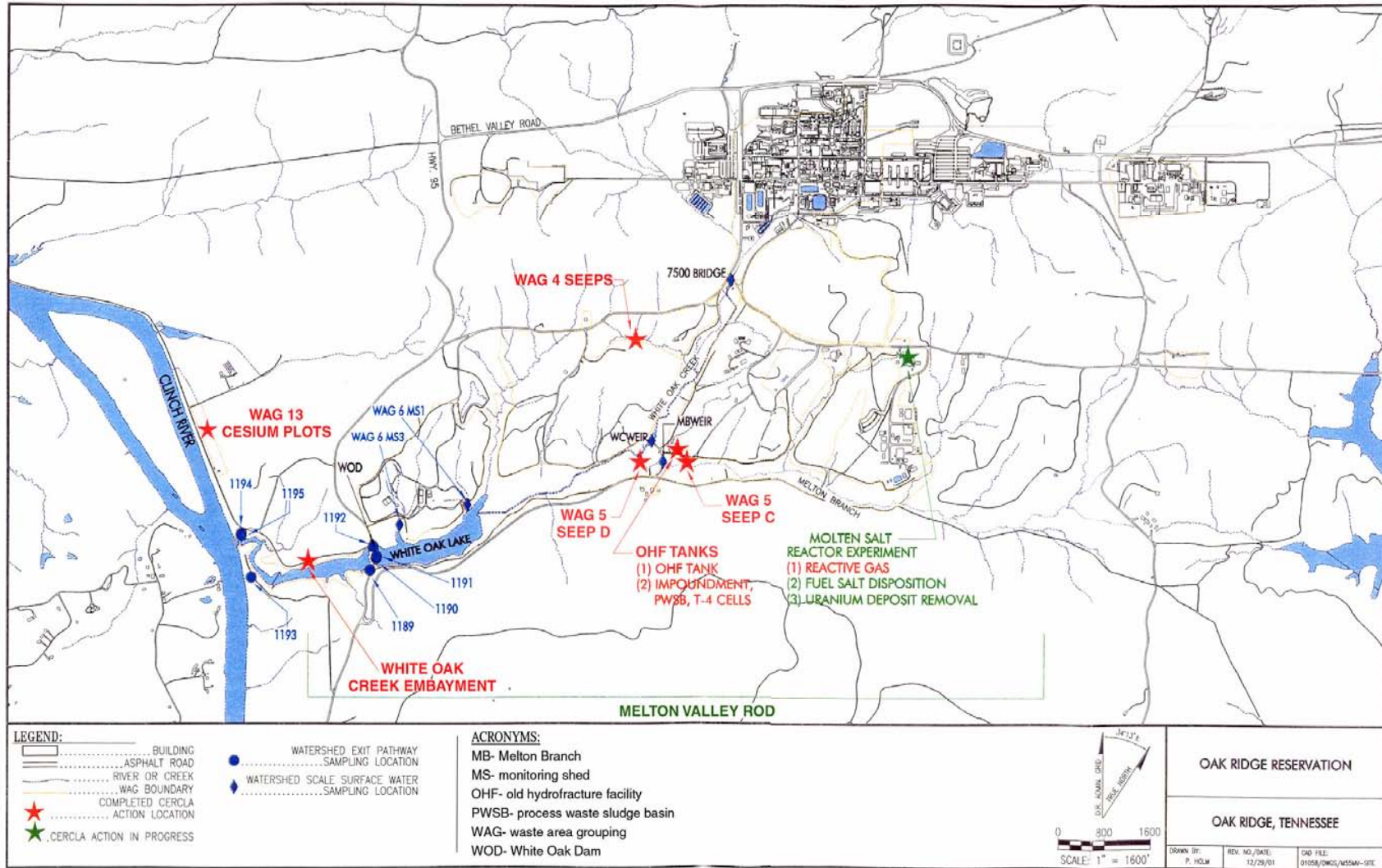
II.C.3. Off-Site Locations

This section discusses remedial activities that have been conducted at two off-site locations related to X-10 that are located within the White Oak Creek Public Health Assessment study area: the Clinch River/Poplar Creek Operable Unit (OU) and the Lower Watts Bar Reservoir OU (SAIC 2002). The White Oak Creek study area (see Figure 11) consists of the area along the Clinch River, from the Melton Hill Dam to the Watts Bar Dam. The Lower Watts Bar Reservoir is downstream of the ORR, extending from the confluence of the Clinch and Tennessee Rivers to the Watts Bar Dam (USDOE 1995a). As a result, the Clinch River and the Lower Watts Bar Reservoir have received contaminants related to X-10 operations (Jacobs EM Team 1997b; USDOE 1995a; USDOE 2001a). See Figure 1 and Figure 4 for these surface water locations.

Remedial actions at the Clinch River/Poplar Creek OU and the Lower Watts Bar Reservoir OU, which were undertaken to protect human health and the environment in the present and future, comply with federal and state guidelines (Jacobs EM Team 1997b; USDOE 1995a). Remedial activities at these OUs are summarized below.

- *Clinch River/Poplar Creek.* The Clinch River/Poplar Creek OU consists of the biota and sediments in the Melton Hill Reservoir and the Watts Bar Reservoir from CRM 0.0 (where the Tennessee and Clinch Rivers join) to CRM 43.7, which is upstream of Melton Hill Dam. In addition, the OU contains the Poplar Creek embayment from the mouth of Poplar Creek along the Clinch River (at CRM 12.0) to its joining with East Fork Poplar Creek (at Poplar Creek mile [PCM] 5.5). All of the Poplar Creek sections of the OU are within the borders of the ORR (SAIC 2002; USDOE 2001a).

Figure 12. Map of the Major Remedial Activities in Melton Valley



Source: SAIC 2002

In 1996, a remedial investigation/feasibility study (RI/FS) was conducted to examine the past and present releases to off-site surface water and to determine if remedial action was necessary (ATSDR et al. 2000). The RI/FS concluded that the Clinch River/Poplar Creek OU presented two main risks by exposure to 1) fish tissue that contained chlordane, mercury, PCBs, and arsenic; and 2) deep sediments in the primary river channel that contained arsenic, mercury, cesium 137, and chromium (Jacobs EM Team 1997b; Jacobs Engineering Group Inc. 1996; SAIC 2002; USDOE 2001a). The largest concentrations of radionuclides that have been detected are buried between 8 and 32 inches into the deep sediments (Jacobs EM Team 1997b).

A baseline risk assessment was conducted. It suggested that consumption of certain fish contaminated with PCBs posed the greatest risk to public health. In addition, fish contaminated with chlordane, mercury, and arsenic presented the possible chance of causing health effects. The assessment also determined that because of PCB and mercury contamination, the consumption of any type of fish in Poplar Creek posed a health risk. Similarly, consumption of bass from the Clinch River below Melton Hill Dam posed a health risk due to PCB contamination. Still, no primary risks were associated with exposure to radionuclides in fish from the Clinch River or from Poplar Creek. Furthermore, the risk assessment determined that contaminants in deep-water sediments would present a health risk only if they were dredged; no exposure pathway currently exists to the deep-water sediments (Jacobs EM Team 1997b).

In September 1997, DOE issued a Record of Decision for the Clinch River/Poplar Creek OU. EPA and TDEC—supportive agencies for this response action—agree with the remedial actions selected for this OU. The chosen actions, which comply with federal and state requirements, were undertaken to protect human health and the environment in the present and future. The following remedial actions were selected for the OU:

1. yearly monitoring to assess fluctuations in concentration levels and contaminant dispersion,
2. advisories on fish consumption,
3. surveys to gauge the usefulness of the fish advisories, and
4. institutional controls to restrict activities that could unsettle the sediment (Jacobs EM Team 1997b; SAIC 2002; USDOE 2001a; USEPA 2002a).

These institutional controls are developed under an interagency agreement (IAG) established by DOE, EPA, TVA, TDEC, and the U.S. Army Corps of Engineers (USACE) in February 1991. The IAG allows these agencies to work cooperatively through the Watts Bar Interagency Agreement to review permitting and all other activities that could result in disturbing the sediment (for example,

In February 1991, DOE, EPA, TVA, TDEC, and USACE established an interagency agreement. Under this agreement, these agencies collaboratively work through the Watts Bar Interagency Agreement to review permitting and other activities that could possibly disturb sediment, such as erecting a pier or building a dock (ATSDR 1996; Jacobs EM Team 1997b; USDOE 2003a). For more details, see the ROD at <http://www.epa.gov/superfund/sites/rods/fulltext/r0497075.pdf>.

building a dock or erecting a pier) (ATSDR 1996; Jacobs EM Team 1997b; USDOE 2003a). Please see page 3-12 of the ROD at <http://www.epa.gov/superfund/sites/rods/fulltext/r0497075.pdf> for more details. For additional information on institutional controls to prevent sediment-disturbing activities, please see *Rules of the Tennessee Department of Environment and Conservation, Chapter 1200-4-7, Aquatic Resource Alteration Permit Process; Section 26A of the Tennessee Valley Authority Act of 1933; and Section 10 of the Rivers and Harbors Act of 1910 (U.S.A.C.E.)* (Jacobs EM Team 1997b).

In February 1998, a Remedial Action Report (RAR) was approved. This report recommended that monitoring be conducted for surface water, fish, sediment, and turtles in the Clinch River/Poplar Creek OU (ATSDR et al. 2000). Since this time, annual surface water sampling, sediment monitoring, and fish and turtle sampling have been conducted at the Clinch River/Poplar Creek OU (SAIC 2002; USDOE 2001a). Institutional controls are also used to examine activities that could result in movement of the sediments, and the Tennessee Wildlife Resources Agency (TWRA) prints fish consumption advisories in its *Tennessee Fish Regulations* (SAIC 2002).

- *Lower Watts Bar Reservoir.* The Lower Watts Bar Reservoir OU stretches from the confluence of the Tennessee River and the Clinch River downstream to the Watts Bar Dam. All surface water and sediment released from the ORR enter the Lower Watts Bar Reservoir OU (SAIC 2002; USDOE 2001a; USDOE 2003c). In 1995, a RI/FS was conducted to assess the level of contamination in the Watts Bar Reservoir, to create a baseline risk assessment based on the contaminant levels, and to determine if remedial action was necessary (ATSDR et al. 2000). The RI/FS revealed that discharges of radioactive, inorganic, and organic pollutants from the ORR have contributed to biota, water, and sediment contamination in the Lower Watts Bar Reservoir (ATSDR et al. 2000; SAIC 2002; USDOE 2001a, 2003b). The baseline risk assessment indicated that standards for environmental and human health would not be reached if deep channel sediments with cesium 137 were dredged and placed in a residential area, and if people consumed moderate to high quantities of specific fish that contained increased levels of PCBs (ATSDR et al. 2000; Environmental Sciences Division et al. 1995).

In September 1995, DOE issued a Record of Decision for the Lower Watts Bar Reservoir OU. EPA and TDEC, which are supportive agencies for this response action, agree with the remedial actions selected for this OU. The chosen actions were undertaken to protect human health and the environment in the present and future, and comply with federal and state requirements. The following contaminants of concern (COCs) were identified at the OU: 1) mercury, arsenic, PCBs, chlordane, and aldrin in fish; 2) mercury, chromium, zinc, and cadmium in dredged sediments and sediments used for growing food products; and 3) manganese through ingestion of surface water (ATSDR et al. 2000; SAIC 2002; USDOE 2001a, 2003b). The largest threat to public health from the Lower Watts Bar Reservoir is related to the consumption of PCB-contaminated fish (SAIC 2002; USDOE 2001a, 2003b). The ROD concluded that if the deep sediments were kept in place, then "...these sediments do not pose a risk to human health because no exposure pathway exists (USDOE 1995a)."

The remedial activities selected for the Lower Watts Bar Reservoir have included using preexisting institutional controls to decrease contact with contaminated sediment, fish

consumption advisories printed in the *Tennessee Fish Regulations*, and yearly monitoring of biota, sediment, and surface water (ATSDR et al. 2000; SAIC 2002; USDOE 1995a, 2001a, 2003b; USEPA 2002a). The interagency agreement established by DOE, EPA, TVA, TDEC, and USACE in February 1991 allows these agencies to work cooperatively through the Watts Bar Interagency Agreement to review permitting and all other activities that could result in disturbing the sediment, such as building a dock or erecting a pier (ATSDR 1996; Jacobs EM Team 1997b; USDOE 2003a). According to the interagency agreement, DOE is required to take action if an institutional control is not effective or if a sediment-disturbing activity could cause harm (Jacobs EM Team 1997b; USDOE 2003a). For more details, please see page 3-5 of the Lower Watts Bar Reservoir ROD at <http://www.epa.gov/superfund/sites/rods/fulltext/r0495249.pdf> and the Clinch River/Poplar Creek OU ROD at <http://www.epa.gov/superfund/sites/rods/fulltext/r0497075.pdf>. For additional information on institutional controls to prevent sediment-disturbing activities, please see *Rules of the Tennessee Department of Environment and Conservation, Chapter 1200-4-7, Aquatic Resource Alteration Permit Process; Section 26A of the Tennessee Valley Authority Act of 1933; and Section 10 of the Rivers and Harbors Act of 1910 (U.S.A.C.E.)* (Jacobs EM Team 1997b).

- In September 1999 DOE combined the *Clinch River/Poplar Creek and Lower Watts Bar Reservoir* operable units for monitoring purposes. These surface water bodies comprise a hydrologically connected system through which ORR contaminants could be transported. A review of sampling conducted to 2004 revealed that no chemical or radiological contaminants in surface water or near-shore sediments posed an unacceptable risk to humans. As a result of these findings, in fiscal year 2004 the previously established long-term monitoring program was modified. The new program, scheduled to commence in fiscal year 2005, requires sediment, surface water, and turtle sampling every 5 years (instead of annually); fish sampling will continue on an annual basis. As appropriate, DOE will supplement the data it collects under the revised monitoring program with sediment and surface water sampling data collected by TVA, TDEC, and TWRA (SAIC 2005).

II.D. Land Use and Natural Resources

When the government acquired the ORR in 1942, it reserved a section of the reservation (about 14,000 acres out of the total of approximately 58,575) for housing, businesses, and support services (ChemRisk 1993c; ORNL et al. 2002). In 1959, that section of the ORR was turned into the independently governed city of Oak Ridge. This self-governing area has parks, homes, stores, schools, offices, and industrial areas (ChemRisk 1993c).

The majority of residences in Oak Ridge are located along the northern and eastern borders of the ORR (Bechtel Jacobs Company LLC et al. 1999). Since the 1950s, however, the urban population of Oak Ridge has grown toward the west. As a result of this expansion, the property lines of many homes in the city's western section border the ORR property (Faust 1993). Apart from these urban sections, the areas close to the ORR continue to be mainly rural, as they have

historically been (Bechtel Jacobs Company LLC et al. 1999; ChemRisk 1993c). The closest homes to X-10 are located near Jones Island, about 2.5 to 3.0 miles southwest of the main facility (ChemRisk 1993c).

In 2002, the ORR measured 34,235 acres, which includes the three main DOE facilities: Y-12, X-10, and K-25 (ORNL et al. 2002). The majority of the ORR is situated within the city limits of Oak Ridge. These DOE facilities constitute approximately 30% of the reservation; the remaining 70% of the reservation was turned into the National Environmental Research Park in 1980. This park was created so that protected land could be used for environmental education and research, and to show that the development of energy technology could be compatible with a quality environment (EUWG 1998). A large amount of land at the ORR that was formerly cleared for farmland has grown into full forests over the past several decades. Sections of this land contain areas called “deep forest” that include flora and fauna considered ecologically significant, and portions of the reservation are regarded as biologically rich (SAIC 2002).

Today, the entire ORNL site encompasses approximately 26,580 acres. The main operations at the ORNL take place on about 4,250 acres, which was formerly known as the X-10 site. The remaining acres are divided between the Oak Ridge National Environmental Research Park (21,980 acres) and the Solway Bend area that is used for environmental monitoring (350 acres) (ORNL et al. 1999). The X-10 site contains approximately 517 buildings, trailers, and additional facilities, which total over 3.4 million square feet. There are additional facilities related to X-10 operations, but these are situated at the Y-12 plant and at off-site locations. Of the X-10 facilities and those at the other locations, however, 156 are inactive or are expected to be inactive in the future (Bechtel Jacobs Company LLC et al. 1999).

Historically, forestry and agriculture (beef and dairy cattle) have constituted the primary uses of land in the area around the reservation; but these land uses are both declining. For several years, milk produced in the area was bottled for local distribution, whereas beef cattle from the area were sold, slaughtered, and nationally distributed. In addition, tobacco, soybeans, corn, and wheat were the primary crops grown in the area. Also, small game and waterfowl were hunted on a regular basis in the ORR area, but deer were hunted during specific time periods. Waterfowl and small game hunting regularly occurs within the ORR area, while deer hunting occurs

annually on the ORR (ChemRisk 1993c). During the annual deer hunts, radiological monitoring is conducted on all deer prior to their release to the hunters. Monitoring is conducted to ensure that none of the animals contain quantities of radionuclides that could cause “significant internal exposure” to the consumer (Teasley 1995).

The southern and western boundaries of the ORR are formed by the Clinch River; Poplar Creek and East Fork Poplar Creek drain the ORR to the north and west (Jacobs EM Team 1997b).

White Oak Creek, which travels south along the eastern border of the X-10 site, flows into White Oak Lake, over White Oak Dam, and into the White Oak Creek Embayment before meeting the Clinch River at CRM 20.8 (ChemRisk 1993b, 1999a; TDOH 2000; USDOE 2002a). Ultimately, every surface water system on the reservation drains into the Clinch River (ChemRisk 1993b).

The Lower Watts Bar Reservoir is situated downstream of the ORR, extending from the confluence of the Clinch and Tennessee Rivers to the Watts Bar Dam (USDOE 1995a). As a result, the Clinch River and the Lower Watts Bar Reservoir have received contaminants associated with X-10 operations (Jacobs EM Team 1997b; USDOE 1995a; USDOE 2001a).

Please see Figure 4 for these relative water systems.

The majority of land around the Clinch River and the Lower Watts Bar Reservoir is undeveloped and wooded. Other than activities at the ORR, there is minimal industrial development in these surrounding areas, and there is a fair amount of residential growth. The public has access to the Clinch River and to the Lower Watts Bar Reservoir, which it uses for recreational purposes such as boating, swimming, fishing, water skiing, and shoreline activities (USDOE 1996d, 2001b, 2003b).

Kingston, Spring City, and Rockwood maintain public water supplies in the vicinity of the Oak Ridge Reservation (Figures 13 and 14 show these water intake and city locations, respectively, that are all within the White Oak Creek study area). The Kingston water supply has two water intakes, but only one of the intakes—located upstream on the Tennessee River in Watts Bar Lake at Tennessee River Mile (TRM) 568.4—would potentially be affected by ORR contaminants (Hutson and Morris 1992; G. Mize, Tennessee Department of Environment and Conservation, Drinking Water Program, personal communication re: Kingston public water supply, 2004). Spring City obtains its water from an intake on the Piney River branch of Watts Bar Lake

(Hutson and Morris 1992). The city of Rockwood receives its water from an intake on the King Creek branch of Watts Bar Lake, located at TRM 552.5 (TDEC 2001, 2006b; TVA 1991). Still, only reverse flow conditions could potentially affect any of these three intakes (ATSDR 1996).

Under the Safe Drinking Water Act, the EPA has since 1974 set health-based standards for substances in drinking water and specified treatments for providing safe drinking water (USEPA 1999a). The public water supplies for Kingston, Spring City, and Rockwood are continually monitored for these regulated substances, which include 15 inorganic contaminants, 51 synthetic and volatile organic contaminants, and 4 radionuclides. For EPA's monitoring schedules, see http://www.epa.gov/safewater/pws/pdfs/qrg_smonitoringframework.pdf (EPA 2004a).

According to EPA's Safe Drinking Water Information System (SDWIS), the Kingston, Spring City, and Rockwood public water supply systems have not had any significant violations (USEPA 2004b). To look up information related to these and other public water supplies, go to EPA's Local Drinking Water Information Web Site at

<http://www.epa.gov/safewater/dwinfo.htm>. In addition,

To ask specific questions related to your drinking water, please call TDEC's Environmental Assistance Center in Knoxville, Tennessee at 865-594-6035. To find additional information related to your water supply or other water supplies in the area, please call EPA's Safe Drinking Water Hotline at 800-426-4791 or visit EPA's Safe Drinking Water Web site at <http://www.epa.gov/safewater>.

in 1996 TDEC's DOE Oversight Division started to participate in EPA's Environmental Radiation Ambient Monitoring System (ERAMS). Under this program, TDEC collects finished drinking water samples from the Kingston Water Treatment Plant on a quarterly basis and then submits the samples to EPA for radiological analyses (TDEC 2002, 2003a). Please see the TDEC-DOE Oversight Division's annual report to the public at <http://www.state.tn.us/environment/doeo/active.shtml> for a summary of radiological drinking water sampling results. TDEC has also conducted filter backwash sludge sampling at Spring City because contaminants from the reservation could potentially move downstream into community drinking water supplies (TDEC 2003b). Additional information on TDEC's participation in the ERAMS program is provided in Section II.F.3. of this document.

II.E. Demographics

The White Oak Creek study area (see Figure 11) consists of the area along the Clinch River, from the Melton Hill Dam to the Watts Bar Dam. Four main cities fall within this area. Three of

the cities—Harriman, Kingston, and Rockwood—are located in Roane County and one of the cities—Spring City—is located in Rhea County. Meigs County is also within the study area. Figure 13 provides the current population distribution in the White Oak Creek Study area, and Figure 14 details current demographic information for areas within ½ mile, 1 mile, and 5 miles of the White Oak Creek study area. There are 13,362 people living within ½ mile, 20,573 people living within 1 mile, and 70,700 people living within 5 miles. For children aged 6 and younger, 983 live within ½ mile, 1,621 live within 1 mile, and 5,812 live within 5 miles.

II.E.1. Counties Within the White Oak Creek Study Area

Since 1940, the populations of Meigs County, Rhea County, and Roane County have all grown by over 50% (Bureau of the Census 1993, 2000). Table 4 presents the population over a 60-year time period for these counties and Figure 15 shows the population distribution over time.

Table 4. Populations of Meigs, Rhea, and Roane Counties From 1940 to 2000

<i>County</i>	<i>1940</i>	<i>1950</i>	<i>1960</i>	<i>1970</i>	<i>1980</i>	<i>1990</i>	<i>2000</i>
Meigs County	6,393	6,080	5,160	5,219	7,431	8,033	11,086
Rhea County	16,353	16,041	15,863	17,202	24,235	24,344	28,400
Roane County	27,795	31,665	39,133	38,881	48,425	47,227	51,910

Source: Bureau of the Census 1993, 2000

Figure 13. Population Distribution in the White Oak Creek Study Area

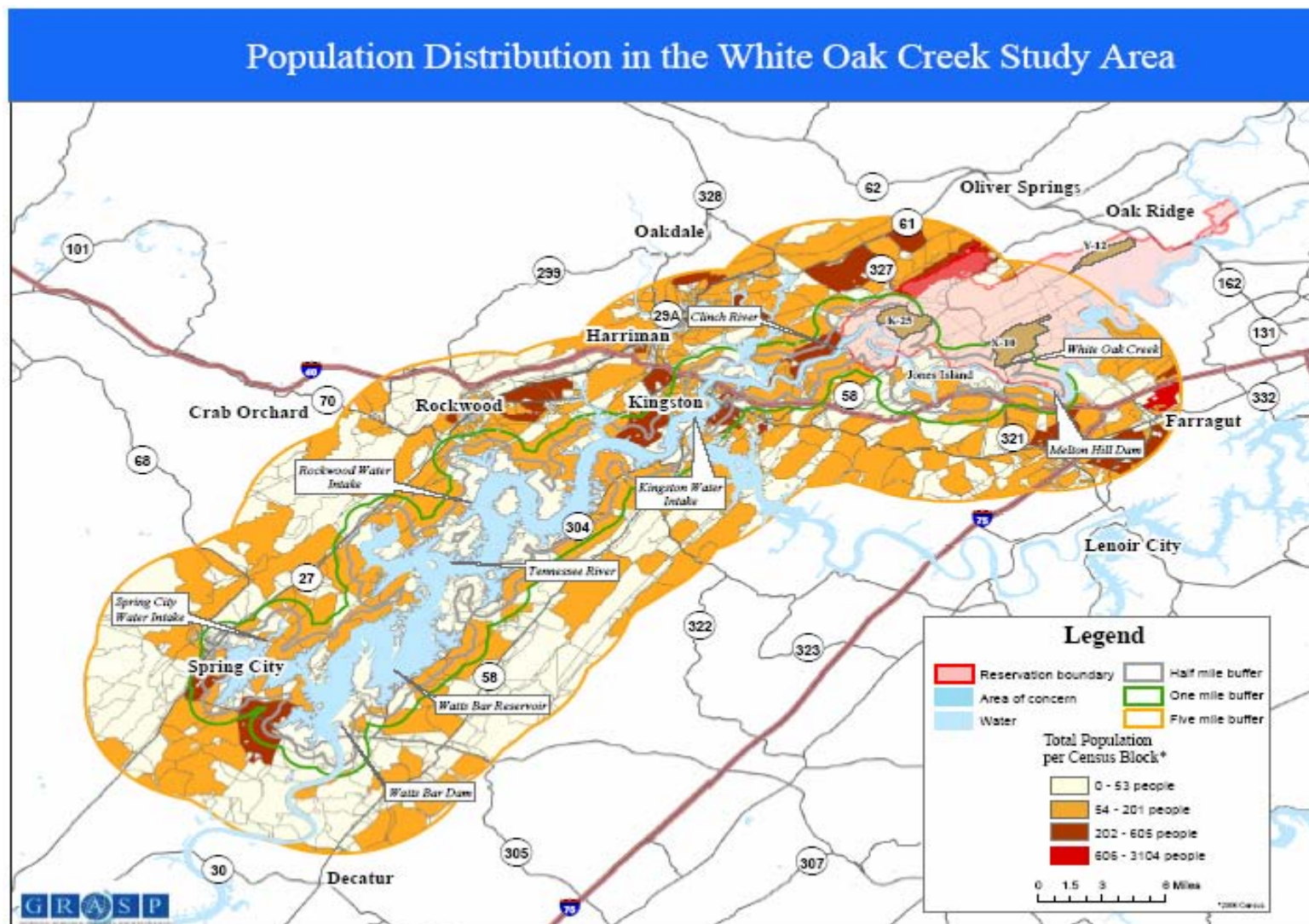


Figure 14. Population Demographics in the White Oak Creek Study Area

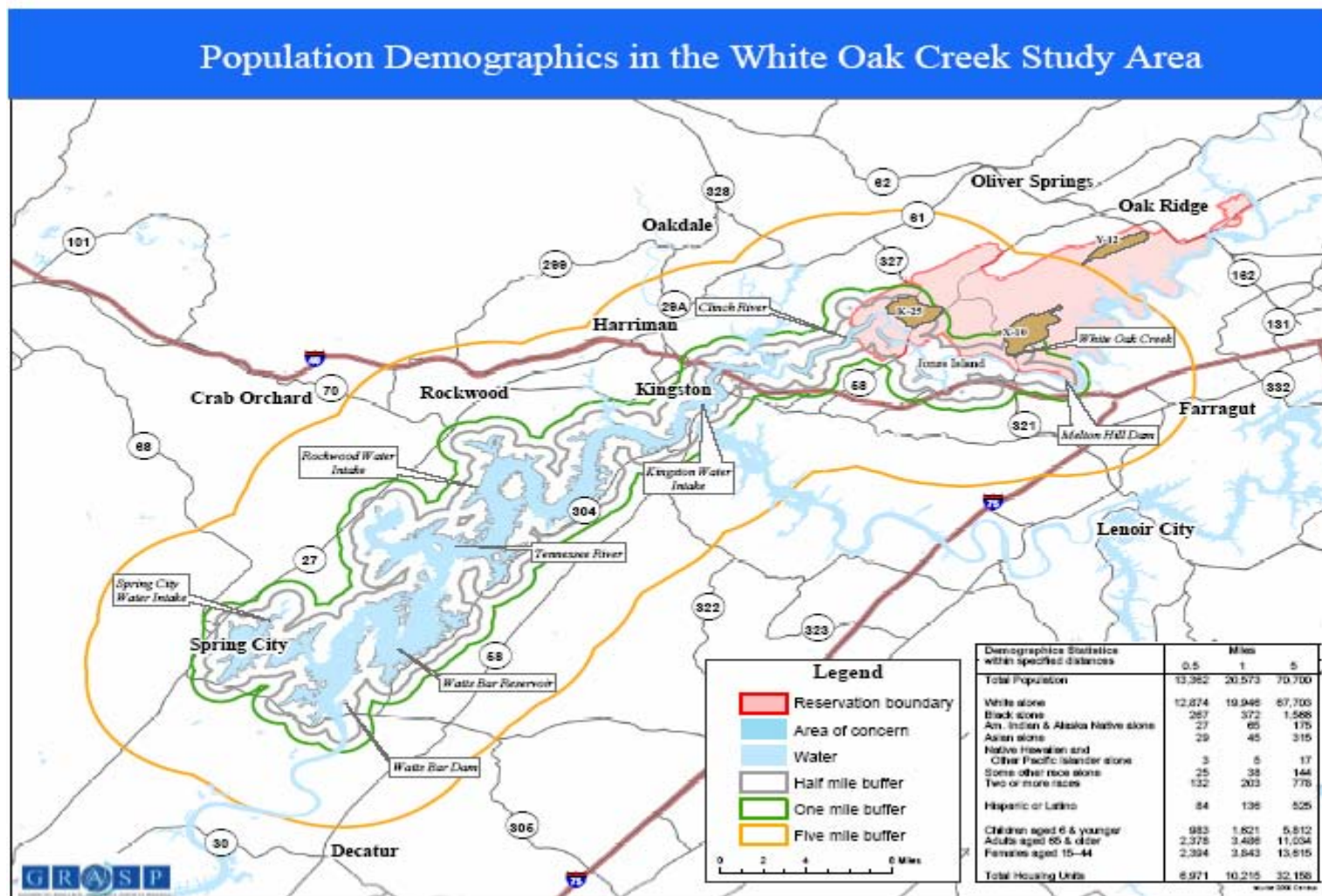
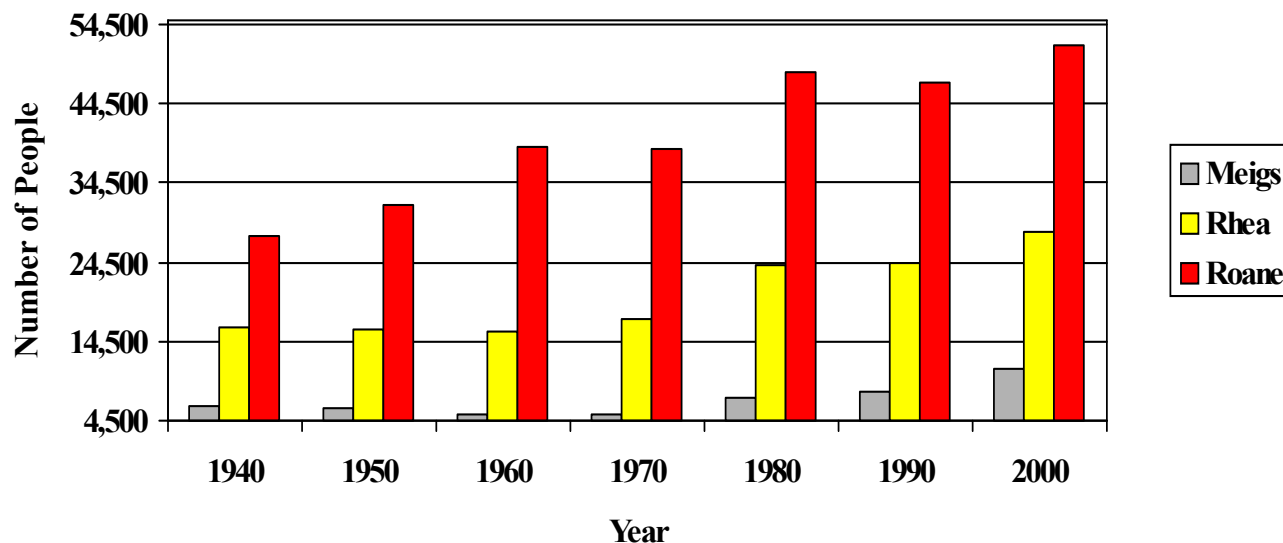


Figure 15. Population Distribution of Meigs, Rhea, and Roane Counties From 1940 to 2000



Source: Bureau of the Census 1993, 2000

Meigs County

Although between 1940 and 1960, the population of Meigs County decreased, the population has more than doubled since that time, increasing from 5,160 to 11,086 (114.8%) (see Table 4 and Figure 15). The largest percentage increase in population occurred between 1970 and 1980, when the number of residents grew from 5,219 to 7,431 (42.4%). Since 1940, the population of Meigs County has grown by almost 75% (Bureau of the Census 1993, 2000). As of 2000, the majority of residents worked in the manufacturing industry. The Meigs County population is comprised of 10,826 Caucasians, 138 African-Americans, and 122 persons of other races. Also, the largest percentage of residents is between the ages of 35 and 44, and the median age is 36.7 (Bureau of the Census 2000).

Rhea County

The population of Rhea County declined between 1940 and 1960, but has continued to increase since the 1960s (see Table 4 and Figure 15). The largest increase (40.9%) occurred between 1970 and 1980, when the number of residents increased from 17,202 to 24,235. Over the past 60 years, the population of Rhea County has increased by nearly 75% (Bureau of the Census 1993, 2000). As of 2000, the majority of residents worked in the manufacturing industry. The Rhea

County population consists of 27,097 Caucasians, 580 African-Americans, and 723 persons of other races. In addition, the largest proportion of residents is between the ages of 35 and 44, with a median age of 37.2 (Bureau of the Census 2000).

Roane County

Over this 60-year period, the population of Roane County has grown by 86.8%, as shown in Table 4 (Bureau of the Census 1993, 2000). Slight declines in population occurred between 1960 and 1970, and between 1980 and 1990 (East Tennessee Development District 1995; Bureau of the Census 1993). Meanwhile, the county population increased during the remaining time periods to reach a population of 51,910 in 2000. Figure 15 shows the population distribution of the county over time (East Tennessee Development District 1995; Bureau of the Census 1993, 2000).

The majority of Roane County's 2000 population is Caucasian (49,440); the remaining portion of the population consists of African-American residents (1,409) and persons of other races (1,061) (Bureau of the Census 2000). Since the 1970s, the median age of Roane County residents has increased from 32.1 to 40.7, suggesting that the county has an aging population (East Tennessee Development District 1995; Bureau of the Census 2000). The X-10 site and the K-25 site are both located within Roane County (East Tennessee Development District 1995; Jacobs EM Team 1997a). Primarily because of these two facilities, between 1940 and 1990 manufacturing was the predominant occupation for Roane County residents (East Tennessee Development District 1995; Bureau of the Census 1993).

II.E.2. Cities Within the White Oak Creek Study Area

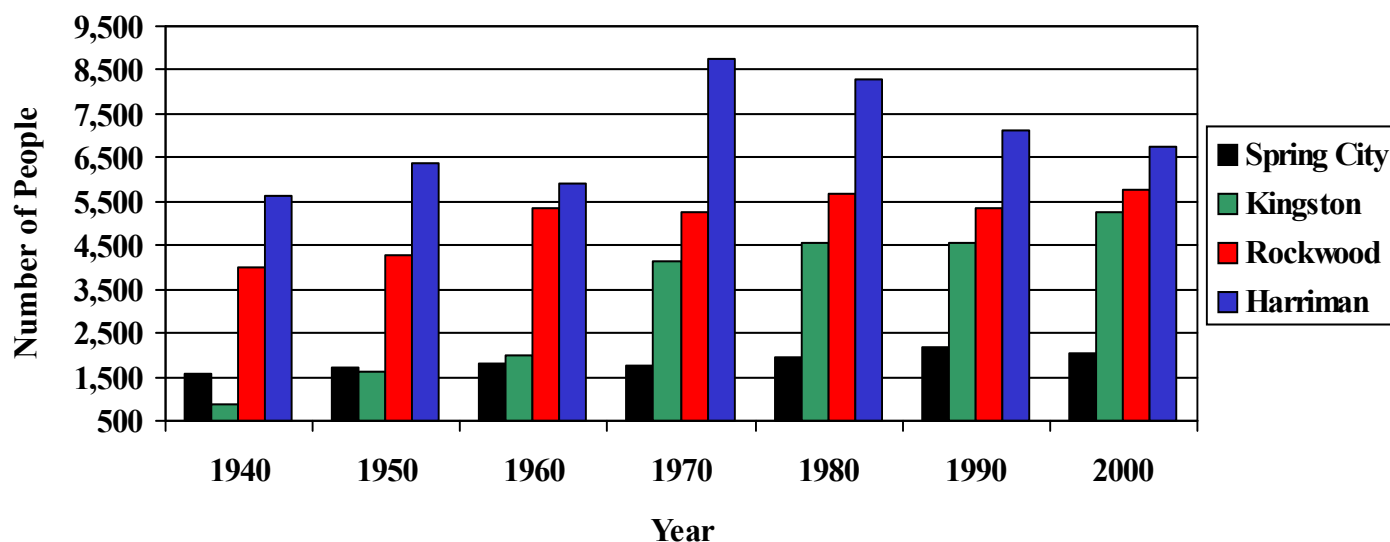
Three cities in the White Oak Creek study area—Kingston, Rockwood, and Harriman—are located in Roane County and Spring City is located in Rhea County. The population of these four cities between 1940 and 2000 (see Table 5), and the population distribution during that time period (see Figure 16) appear below.

Table 5. Populations of Spring City, Kingston, Rockwood, and Harriman From 1940 to 2000

<i>City</i>	<i>1940</i>	<i>1950</i>	<i>1960</i>	<i>1970</i>	<i>1980</i>	<i>1990</i>	<i>2000</i>
Spring City	1,569	1,725	1,800	1,756	1,951	2,199	2,025
Kingston	880	1,627	2,010	4,142	4,561	4,552	5,264
Rockwood	3,981	4,272	5,345	5,259	5,695	5,348	5,774
Harriman	5,620	6,389	5,931	8,734	8,303	7,119	6,744

Source: Bureau of the Census 1940, 1950, 1960, 1970, 1980, 1993, and 2000

Figure 16. Population Distribution of Spring City, Kingston, Rockwood, and Harriman From 1940 to 2000



Source: Bureau of the Census 1940, 1950, 1960, 1970, 1980, 1993, and 2000

Spring City

Spring City is approximately 49 miles southwest of the X-10 site (see Figure 11) (MapQuest 2003). Between 1940 and 2000, the population of Spring City continually fluctuated, as shown in Table 5. During this time period, the number of residents increased between 1940 and 1960 and between 1970 and 1990. The population declined from 1960 to 1970 and from 1990 to 2000. The largest percentage increase in population was seen between 1980 and 1990, followed by the largest decrease between 1990 and 2000 (Bureau of the Census 1940, 1950, 1960, 1970, 1980, 1993, 2000). As of 2000, the largest percentage (31.6%) of residents worked in the

manufacturing industry. The population consists of 1,914 Caucasians, 91 African-Americans, and 20 persons of other races. The highest percentage of the population is between the ages of 35 and 44, and the city's median age is 44.0 (Bureau of the Census 2000).

Kingston

The city of Kingston, which is the seat of Roane County, is located at the confluence of the Clinch River and the Tennessee River (see Figure 11), and it is about 22 miles southwest of the X-10 site (MapQuest 2003). The population of Kingston (see Table 5) has grown steadily from 1940 to 2000, except for a 0.2% decrease between 1980 and 1990 (East Tennessee Development District 1995; Bureau of the Census 1993, 2000). In 1969, the city of Kingston had one manufacturing plant; by 1990, 6 of the 35 manufacturing plants in Roane County were in Kingston (East Tennessee Development District 1995). Since 1990, the greatest portion of residents has been employed in the professional services field (East Tennessee Development District 1995; Bureau of the Census 2000). In 2000, the population consisted of 4,935 Caucasians, 187 African-Americans, and 142 persons of other races. The majority of Kingston residents are between the ages of 45 and 54; the median age is 41.6 (Bureau of the Census 2000).

Rockwood

The city of Rockwood is about 33 miles southwest of the X-10 site (see Figure 11) (MapQuest 2003). The population of Rockwood has fluctuated from 1940 to 2000 (see Table 5). The city experienced steady growth between 1940 and 2000, except for slight declines that occurred between 1960 and 1970 and between 1980 and 1990 (East Tennessee Development District 1995; Bureau of the Census 1993, 2000). In 1969, 10 out of 29 manufacturing plants in Roane County were in Rockwood; by 1990, Rockwood had 13 out of the 35 manufacturing plants in the county (East Tennessee Development District 1995). The largest percentage of residents is employed in the manufacturing field. As of 2000, the Rockwood population consisted of 5,362 Caucasians, 314 African-Americans, and 98 persons of other races. The median age is 42.0, and the greatest portion of individuals is between the ages of 45 and 54 (Bureau of the Census 2000).

Harriman

The city of Harriman is about 24 miles west of the X-10 site (see Figure 11) (MapQuest 2003). As also seen in Table 5, the population of Harriman peaked between 1970 and 1980, and has

continued to decline since that time (East Tennessee Development District 1995; Bureau of the Census 1993, 2000). In 1969, 18 of the 29 manufacturing plants in Roane County were located in the city of Harriman. By 1990, Roane County had 35 manufacturing plants, but the number within Harriman had fallen to 15 (East Tennessee Development District 1995). Still, as of 2000, manufacturing is the leading source of employment for Harriman residents. In 2000, the population consisted of 6,077 Caucasians, 501 African-Americans, and 166 persons of other races. The majority of residents are between the ages of 45 and 54, with the median age of 40.5 (Bureau of the Census 2000). As of 1990, Harriman had more minority residents than any other city in Roane County (East Tennessee Development District 1995).

II.F. Summary of Public Health Activities Pertaining to White Oak Creek Radionuclide Releases

This section describes the public health activities that pertain to radionuclide releases to White Oak Creek from the X-10 site. ATSDR, the TDOH, and other agencies have conducted additional public health activities at the ORR, which are described in Appendix C. Please see Figure 5 for a time line of public health activities related to radionuclide releases from X-10.

II.F.1. ATSDR

Since 1991, ATSDR has addressed the health concerns of community members, civic organizations, and other government agencies by working extensively to determine whether levels of environmental contamination at and near the ORR present a public health hazard. During this time, ATSDR has identified and evaluated several public health issues and has worked closely with many parties, including community members, civic organizations, physicians, and several federal, state, and local environmental and health agencies. While the TDOH conducted the Oak Ridge Health Studies to evaluate whether off-site populations have experienced exposures in the *past*, to prevent duplication of the state's efforts ATSDR's activities focused on *current* and *future* public health issues. The following paragraphs highlight major public health activities conducted by ATSDR that pertain to White Oak Creek radionuclide releases.

Health consultations, exposure investigations, and other scientific evaluations. ATSDR health scientists have addressed current public health issues related to the Watts Bar Reservoir area.

- *Health consultation on the Lower Watts Bar Reservoir, February 1996.* In March 1995, DOE released a proposed plan to address the chemical and radiological contaminants in the Lower Watts Bar Reservoir. DOE's plan called for leaving contaminated sediment in place with the use of institutional controls to prevent disruption of the contaminated sediment. (For example, people must apply for and obtain a permit from TVA, USACE, or TDEC before dredging any sediment in the Lower Watts Bar Reservoir. See Section III.B.3. for more details on the Watts Bar Interagency Agreement and the process to obtain a permit.) Local residents were worried about the contamination in the reservoir and they expressed their concerns about the adequacy of DOE's proposed remedial actions and controls. The residents requested that ATSDR assess the current and future health hazards associated with contaminants left in place in the Lower Watts Bar Reservoir sediment, and as a result, ATSDR conducted a health consultation on the area.

To evaluate the chemical and radiological contaminants in the Lower Watts Bar Reservoir, ATSDR reviewed environmental sampling data from the 1980s and 1990s that had been assembled by DOE, TVA, and various consultants. In addition, ATSDR examined TVA's 1993 and 1994 Annual Radiological Environmental Reports for the Watts Bar nuclear plant. Initially, ATSDR screened the data to determine if any contaminants were present at levels that exceeded health-based comparison values. To determine if current chemical and radiological contaminant levels could potentially affect area residents, ATSDR used both worst-case exposure scenarios and realistic exposure scenarios to estimate the doses for any contaminants that were above the comparison values.

ATSDR uses a comparison value (CV) as a screening level during the public health assessment process. Substances found in amounts greater than their CVs are further evaluated. If a contaminant exceeds its comparison value, it does not necessarily mean that the contaminant will cause adverse health effects. Comparison values are used to help ATSDR determine which contaminants need to be evaluated more closely.

ATSDR found that only polychlorinated biphenyls (PCBs) in the Lower Watts Bar Reservoir fish presented a public health concern. The agency found that frequent and long-term consumption of reservoir fish could moderately increase a person's chance of cancer, and that reservoir turtles could also contain PCBs at levels of public health concern (ATSDR et al. 2000).

ATSDR also determined that present contaminant levels in the reservoir sediment and surface water were not of public health concern—the reservoir was safe for recreational activities, such as skiing, swimming, and boating, and the municipal water was safe to drink. Furthermore, ATSDR reviewed the DOE's remedial action plan and concluded the remedial actions were protective of public health. These remedial actions included continuing environmental monitoring; maintaining the fish consumption advisories; and implementing institutional controls to prevent resuspension, removal, disruption, or disposal of contaminated sediment (ATSDR et al. 2000). For more specific details on the findings of ATSDR's health consultation, see Section III.B.3. and Appendix D.

Given its findings, ATSDR made the following recommendations:

1. To minimize exposure to PCBs, the Lower Watts Bar Reservoir fish advisory should remain in effect.
 2. ATSDR should work with the state of Tennessee to implement a community health education program on the Lower Watts Bar fish advisory and on the health effects of PCB exposure.
 3. The likelihood of health effects from consumption of turtles in the Lower Watts Bar Reservoir should be evaluated. The evaluation should investigate turtle consumption patterns and PCB levels in edible portions of turtles.
 4. Surface and subsurface sediments should not be disturbed, removed, or disposed of without careful review by the interagency working group (this working group was previously discussed in Section II.C.3.).
 5. Sampling of municipal drinking water at regular intervals should be continued. In addition, if a significant release of contaminants from the ORR is discharged into the tributaries of the Clinch River at any time, DOE should notify the municipal water systems and monitor surface water intakes.
- *Watts Bar Reservoir exposure investigation, March 1998.* Prior to this exposure investigation, studies on the Watts Bar Reservoir and on the Clinch River had reviewed several contaminants, but the only contaminant found to be of current public health concern was PCBs in reservoir fish. These past studies, which include DOE's remedial investigations on the Lower Watts Bar Reservoir (1994) and on the Clinch River/Poplar Creek (1996), as well as ATSDR's 1996 Health Consultation on the Lower Watts Bar Reservoir, based their findings on estimated PCB exposure doses and estimated increases of cancer likelihood after consuming large amounts of fish over extended time periods. Mainly, ATSDR conducted this exposure investigation because of the uncertainties associated with estimating exposure doses and with estimating increases in cancer likelihood from ingestion of reservoir fish and turtles. In addition, these past investigations did not confirm that people were actually being exposed or that they had elevated PCB or mercury levels. Also, a TDOH contractor suggested conducting an extensive, region-wide evaluation to assess the relevant exposures and health effects in counties surrounding the Watts Bar Reservoir (Thapa 1996). ATSDR believed, however, that before any agency conducted extensive investigations it should determine if mercury and PCBs were actually elevated in individuals who consumed large amounts of fish and turtles from the reservoir.

Exposure investigations are one of the public health approaches that ATSDR used to develop a better characterization of past, present, or possible future human exposure to hazardous substances in the environment. These investigations only evaluate exposures and do not assess whether exposure levels resulted in adverse health effects.

The ATSDR exposure investigation evaluated exposures at one point in time (data and samples were collected September 15–28, 1997). Because, however, serum PCB levels are an indicator of chronic exposure (more than 1 year) and mercury blood levels are an indicator of intermediate exposure (from 15 days to less than 1 year), the investigation results provide information on both past and present exposure. ATSDR focused its evaluation on individuals who consumed moderate to high amounts of fish and turtles from the Watts Bar Reservoir. Participants were recruited through fishing licenses, newspaper, radio, and television announcements, as well as through posters and flyers placed at various fishing-related locations (e.g., bait shops). ATSDR interviewed more than 550 volunteers; 116 of these individuals had consumed enough fish or turtles to be included in the investigation. A brief summary of this exposure investigation is provided in Appendix D.

The results of this investigation were disseminated to the public through a mailing and in a public forum. ATSDR concluded that the participants' serum PCB levels and blood mercury levels were consistent with those seen in the general population. The three major findings are listed below (ATSDR et al. 2000; ORHASP 1999):

1. The investigation participants' serum PCB levels and blood mercury levels were very similar to levels seen in the general population.
2. Of the 116 people tested, only 5 (4%) had serum PCB levels above 20 micrograms per liter ($\mu\text{g/L}$) or parts per billion (ppb), the level regarded as elevated for total PCBs. Four of the five participants who exceeded 20 $\mu\text{g/L}$ had levels between 20 and 30 $\mu\text{g/L}$. One participant had a serum PCB level that measured 103.8 $\mu\text{g/L}$, which is above the distribution seen in the general population. Follow-up counseling was given to study participants with elevated PCB blood levels. Through this counseling, researchers were able to investigate other potential past exposure routes and to recommend behaviors that could reduce future exposure.
3. One investigation participant had a total blood mercury level above 10 $\mu\text{g/L}$, which is regarded as elevated. The other participants had mercury blood levels that varied up to 10 $\mu\text{g/L}$, which would be likely in the general population. Follow-up counseling was also given to this person.

Community and physician education on PCBs in fish, September 1996. As a follow-up to the recommendations in the Lower Watts Bar Reservoir Health Consultation, ATSDR created a program to educate the community and physicians on PCBs in the Watts Bar Reservoir. On September 11, 1996, Daniel Hryhorczuk, MD, MPH, ABMT, from the Great Lakes Center at the University of Illinois at Chicago, presented information on the health risks related to the consumption of PCBs in fish. Dr. Hryhorczuk made his presentation to about 40 area residents at the community health education meeting in Spring City, Tennessee. In addition, on September 12, 1996, an educational meeting for health care providers in the Watts Bar Reservoir area was held at the Methodist Medical Center in Oak Ridge, Tennessee. Furthermore, ATSDR

collaborated with local residents, associations, and state officials to create a brochure informing the public about TDEC's fish consumption advisories for the Watts Bar Reservoir (ATSDR et al. 2000).

Coordination with other parties. Since 1992 and continuing to the present, ATSDR has consulted regularly with representatives of other parties involved with the ORR. Specifically, ATSDR has coordinated its efforts with TDOH, TDEC, the National Center for Environmental Health (NCEH), the National Institute for Occupational Safety and Health (NIOSH), the Health Resources and Services Administration (HRSA), and DOE. These coordinated efforts led to the establishment of the Public Health Working Group in 1999, and then to the formation of the Oak Ridge Reservation Health Effects Subcommittee (ORRHES). In addition, ATSDR provided some assistance to TDOH in its study of past public health issues (ATSDR et al. 2000).

Oak Ridge Reservation Health Effects Subcommittee. The ORRHES was established in 1999 by ATSDR and the Centers for Disease Control and Prevention (CDC) under the authority of the Federal Advisory Committee Act (FACA), and as a subcommittee of the U.S. Department of Health and Human Services' Citizens Advisory Committee on Public Health Service Activities and Research at DOE sites. The subcommittee consisted of people who represented diverse interests, expertise, backgrounds, and communities, as well as liaison members from federal and state agencies. It was a forum for communication and collaboration between the citizens and the agencies that evaluate public health issues and conduct public health activities at the ORR. To help ensure citizen participation, the meetings of the subcommittee's work groups were open to the public, and everyone was invited to attend and present their ideas and opinions. The subcommittee performed the following functions:

- Served as a citizen advisory group to CDC and to ATSDR and made recommendations on matters related to public health activities and research at the ORR.
- Allowed citizens an opportunity to collaborate with agency staff members and to learn more about the public health assessment process and other public health activities.
- Helped to prioritize the public health issues and community concerns evaluated by ATSDR.

The ORRHES created various work groups that conducted in-depth exploration of specific issues and presented findings to the subcommittee for deliberation. Work group meetings were open to all who wished to attend and participate. Figure 17 shows the organizational structure of the

ORRHES, and Figure 18 is a chart that shows the process of providing input into public health assessments. For more information on the ORRHES, visit the ORRHES Web site at www.atsdr.cdc.gov/HAC/oakridge (ATSDR et al. 2000).

ATSDR field office. ATSDR maintained a field office in the city of Oak Ridge from 2001 to 2005. The office was opened to promote collaboration between ATSDR and the communities surrounding the ORR by providing community members with opportunities to become involved in ATSDR's public health activities at the ORR (ATSDR et al. 2000).

Where can one obtain more information on ATSDR's activities at Oak Ridge?

ATSDR has conducted several additional analyses that are not documented here or in Appendix C, as have other agencies that have been involved with this site. Community members can find more information on ATSDR's past activities by the following three ways:

1. *Visit one of the records repositories.* Copies of ATSDR's publications on the ORR, along with publications from other agencies, can be viewed in records repositories at public libraries and the DOE Information Center in Oak Ridge. For directions to these repositories, please contact ATSDR at 1-888-42ATSDR (or 1-888-422-8737).
2. *Visit the ATSDR or ORRHES Web sites.* These Web sites include our past publications, schedules of future events, and other information materials. ATSDR's Web site is at www.atsdr.cdc.gov and the ORRHES Web site is at www.atsdr.cdc.gov/HAC/oakridge. The most comprehensive summary of past activities can be found at <http://www.atsdr.cdc.gov/HAC/oakridge/phact/index.html>.
3. *Contact ATSDR directly.* Residents can contact representatives from ATSDR directly by dialing the agency's toll-free number, 1-888-42ATSDR (or 1-888-422-8737).

Figure 17. Organizational Structure for the Oak Ridge Reservation Health Effects Subcommittee

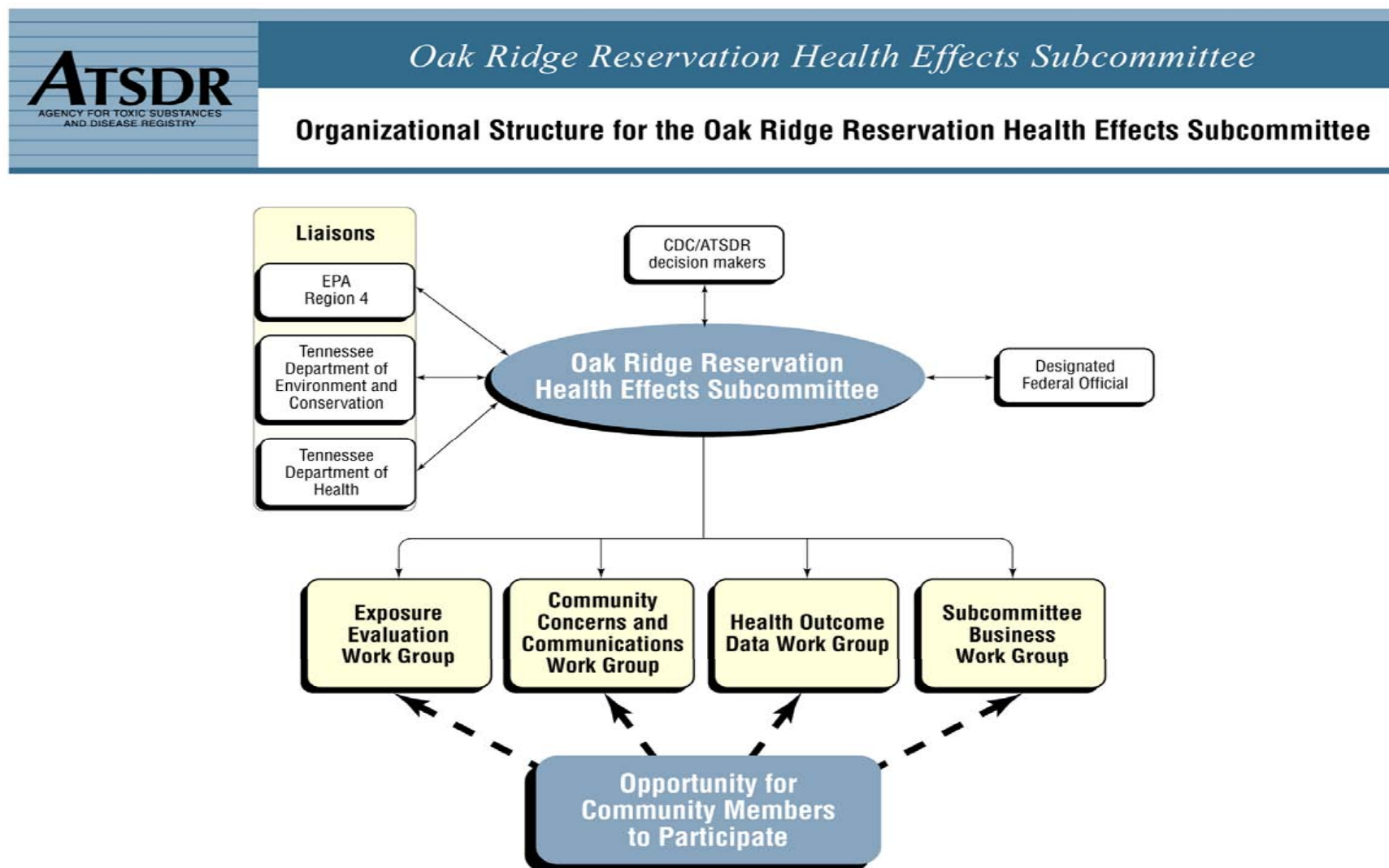
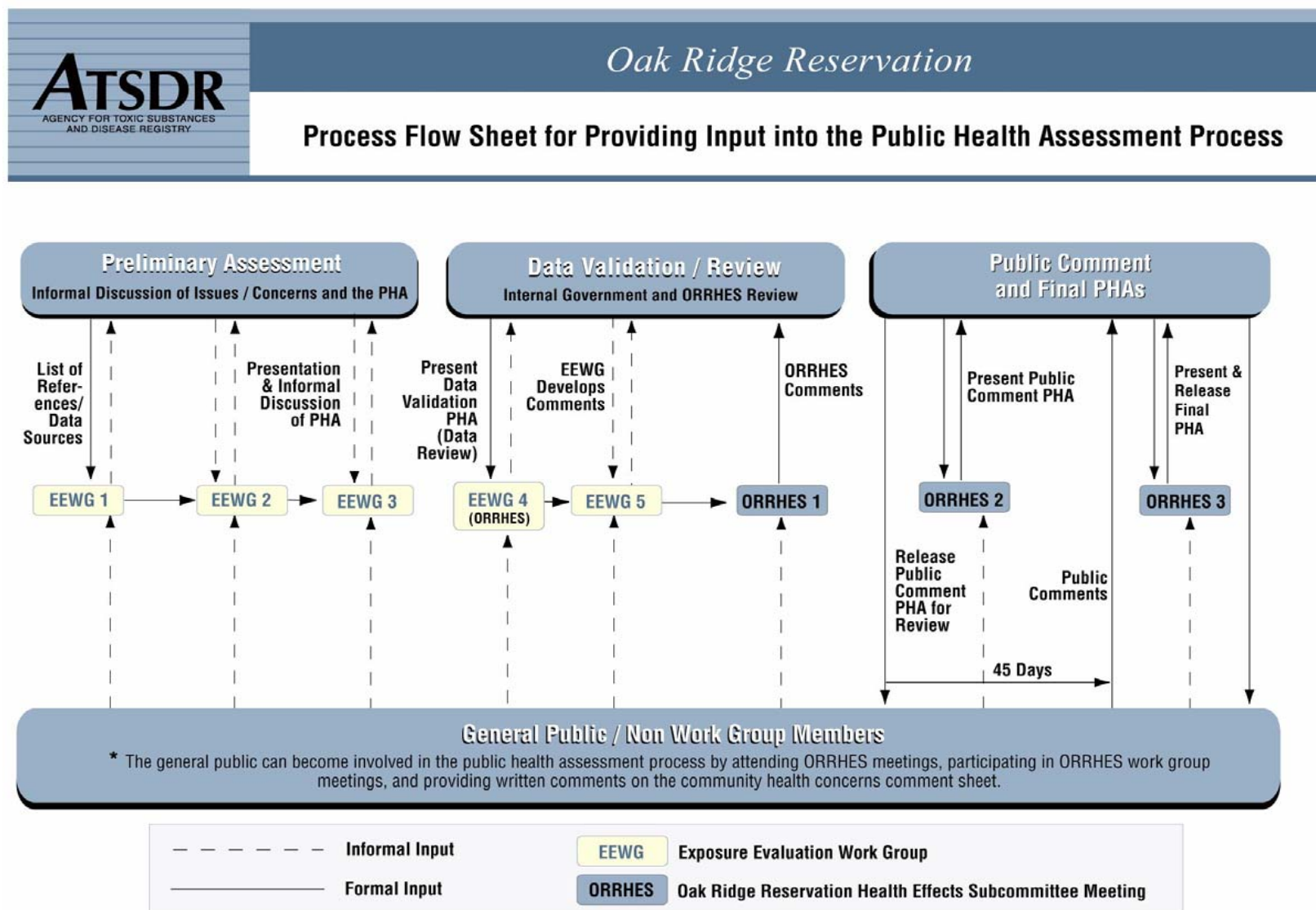


Figure 18. Process Flow Sheet for Providing Input Into the Public Health Assessment Process



II.F.2. TDOH

Oak Ridge Health Studies. In 1991, DOE and the state of Tennessee entered into the Tennessee Oversight Agreement, which allowed the TDOH to undertake a two-phase independent state research project to determine whether past environmental releases from ORR operations harmed people who lived nearby (ORHASP 1999). All of the technical reports produced for the TDOH Oak Ridge Health Studies are accessible in portable document format (PDF) at

<http://cedr.lbl.gov>.

- *Phase I.* Phase I of the Oak Ridge Health Study is a Dose Reconstruction Feasibility Study. This feasibility study evaluated all past releases of hazardous substances and operations at the ORR. The objective of the study was to determine the quantity, quality, and potential usefulness of the available information and data on these past releases and subsequent exposure pathways. Phase I of the health studies began in May 1992 and was completed in September 1993 (ATSDR et al. 2000). A brief summary of the Phase I Feasibility Study is provided in Appendix D.

During this process, the state reviewed thousands of documents and interviewed knowledgeable parties to assess the possibility of creating a dose reconstruction, and to examine historical releases from the ORR that posed the greatest threat to public health. The state reviewed documents related to four major facilities, X-10 (now ORNL), Y-12, K-25, and the former S-50, and for several off-site areas associated with ORR contamination (ChemRisk 1993a, 1999a). In the feasibility study, the state 1) evaluated historical activities at each facility on the ORR, 2) compiled an inventory of environmental sampling and research data for use in the dose reconstruction, 3) identified activities with the highest potential to release substantial quantities of contaminants to off-site populations, 4) determined the potential that the contaminants released could affect public health, 5) identified important environmental media and exposure pathways through which off-site populations could be exposed, 6) compiled a list of contaminants that needed further evaluation, 7) examined if a completed exposure pathway existed, and 8) assessed which pathways contributed significantly to the potential health risks for off-site populations. Through this extensive process, ChemRisk was able to identify the contaminants and pathways with the greatest likelihood for causing adverse health effects. *For information on other activities conducted during the feasibility study, please see ChemRisk's 1993 Oak Ridge Health Studies.*

The findings of the Phase I Dose Reconstruction Feasibility Study indicated that a significant amount of information was available to reconstruct the past releases and potential off-site exposure doses for four hazardous substances that had the largest potential risk for adverse health effects. These four substances include 1) radioactive iodine releases associated with radioactive lanthanum processing at X-10 from 1944 through 1956; 2) mercury releases associated with lithium separation and enrichment operations at the Y-12 plant from 1955 through 1963; 3) PCBs in fish from East Fork Poplar Creek (EFPC), the Clinch River, and

the Watts Bar Reservoir; and 4) radionuclides from White Oak Creek associated with various chemical separation activities at X-10 from 1943 through the 1960s (ATSDR et al. 2000).

- *Phase II (also referred to as the Oak Ridge Dose Reconstruction).* Phase II of the health studies conducted at Oak Ridge began in mid-1994 and was completed in early 1999. Phase II primarily consisted of a dose reconstruction study focusing on past releases of radioactive iodine, radionuclides from White Oak Creek, mercury, and PCBs. In addition to the full dose reconstruction analyses, the Phase II effort also included additional detailed screening analyses for releases of uranium and several other toxic materials that had not been fully characterized in Phase I (a brief in Appendix D summarizes the *Screening-Level Evaluation of Additional Potential Materials of Concern, Task 7*). The significant findings for each of the substances evaluated, as well as the significant findings of the additional screening analyses in the Task 7 report, are presented in the following paragraphs.

Radioactive iodine releases were associated with radioactive lanthanum processing at X-10 from 1944 through 1956. Results indicate that children who were born in the area in the early 1950s and who drank milk produced by cows or goats living in their yards had the highest theoretical increased risk of developing thyroid cancer. The results suggest that a female born in 1952 at Bradbury, Tennessee would have the highest risk of developing thyroid cancer from the radioactive iodine releases.

The study evaluated mercury releases associated with lithium separation and enrichment operations at the Y-12 plant from 1955 through 1963. Results indicate that during the mid-1950s farm families living along East Fork Poplar Creek and children playing in the creek could have received annual average doses of mercury exceeding the EPA reference dose. The results also suggest that fetuses of pregnant women who ate significant quantities of fish from the Clinch River or Poplar Creek in the late 1950s and early 1960s are at the highest risk from methylmercury exposure.

EPA's reference dose is an estimate of the largest amount of a substance that a person can take in on a daily basis over his or her lifetime without experiencing a significant increase in risk of adverse health effects.

Additional studies were conducted on PCBs in fish from EFPC, the Clinch River, and the Watts Bar Reservoir. Preliminary results indicated that individuals who consumed a large amount of fish from these waters might have received doses that exceeded the EPA reference dose for PCBs.

Radionuclides associated with various chemical separation activities at the X-10 site from 1943 through the 1960s were released into White Oak Creek. Initially, TDOH identified eight radionuclides as contaminants of concern: cesium 137, ruthenium 106, strontium 90, cobalt 60, cerium 144, zirconium 95, niobium 95, and iodine 131. Four of these radionuclides were deemed likely to carry significant health risks: cesium 137, cobalt 60, ruthenium 106, and strontium 90. The results indicate that the releases caused small increases in the radiation dose over background for individuals who consumed fish from the Clinch River near the mouth of White Oak Creek. The dose reconstruction scientists estimated that an adult male who annually consumed a maximum of 130 meals of fish caught near the mouth of White Oak Creek and who continued this diet for 50 years (worst-case scenario) had the highest

theoretical increased risk of developing cancer. The risk from eating fish goes down proportionately for people who eat fewer fish and for people who eat fish caught farther downstream. A brief summary of the Task 4 report is provided in Appendix D.

Uranium was released from various large-scale uranium operations, primarily uranium processing and machining operations at the Y-12 plant and uranium enrichment operations at the K-25 and S-50 plants. Because uranium was not initially given high priority as a contaminant of concern, a Level II screening assessment for all uranium releases was performed. Preliminary screening indices for Y-12 and K-25 were below the Oak Ridge Health Agreement Steering Panel (ORHASP) decision guide of one chance in 10,000. A brief summary of the Task 6 report is provided in Appendix D.

The *Screening-Level Evaluation of Additional Potential Materials of Concern* was conducted to determine if contaminants other than those identified in the *Oak Ridge Dose Reconstruction Feasibility Study* warranted further evaluation to assess their potential to cause health effects to off-site populations. Three methods—a qualitative screening, a quantitative screening, and a threshold quantity approach—were used to evaluate the potential for 25 materials or groups of materials to cause off-site health effects. Based on the screening results, 5 materials used at the K-25 plant and 14 materials used at the Y-12 plant warranted no further study. Three materials used at the K-25 plant (copper powder, nickel, and technetium 99), three materials used at the Y-12 plant (beryllium compounds, lithium compounds, and technetium 99), and one material used at the ORR (chromium VI) were determined to be potential candidates for further study. High priority candidates for further study included one material used at the K-25 plant (arsenic) and two materials used at the Y-12 plant (arsenic and lead). A brief summary of the Task 7 report is provided in Appendix D.

The *Oak Ridge Health Agreement Steering Panel (ORHASP)*—a panel of experts and local citizens—was appointed to direct and oversee the Oak Ridge Health Studies and provide liaison with the community. Given the findings of the Oak Ridge Health Studies and what is generally known about the health risks posed by exposures to various toxic chemicals and radioactive substances, ORHASP concluded that, “past releases from the Oak Ridge Reservation were likely to have harmed some people.” Two groups most likely to have been harmed were 1) local children who drank milk produced by a “backyard” cow or goat in the early 1950s and 2) fetuses of women who routinely ate fish from contaminated creeks and rivers downstream of the ORR in the 1950s and early 1960s. ORHASP noted, however, the Task 4 report determined that following exposure to fish contaminated with X-10 radionuclides via White Oak Creek, less than

one excess cancer case was expected. Studies also indicate that elevated PCB concentrations drove the health risks associated with eating fish from the Clinch River and Watts Bar Reservoir. For additional information on the ORHASP findings, please see the final report of the ORHASP titled *Releases of Contaminants from Oak Ridge Facilities and Risks to Public Health* at <http://www2.state.tn.us/health/CEDS/OakRidge/ORHASP.pdf>.

II.F.3. Tennessee Department of Environment and Conservation (TDEC)

Sampling of Public Drinking Water Systems in Tennessee. For 30 years, under the Safe Drinking Water Act of 1974 (summary available at <http://www.epa.gov/safewater/index.html>), the EPA has set health-based standards and specified treatments for substances in public drinking water systems. In 1977, EPA gave the state of Tennessee authority to operate its own Public Water System Supervision Program under the Tennessee Safe Drinking Water Act. Through this program, TDEC's Division of Water Supply regulates drinking water at all public water systems. As a requirement of this program, all public water systems in Tennessee individually monitor their water supply for EPA-regulated contaminants and report their monitoring results to TDEC. The public water supplies for Kingston, Spring City, Rockwood, and other supplies in Tennessee are monitored for substances that include 15 inorganic contaminants, 51 synthetic and volatile organic contaminants, and 4 radionuclides (USEPA 2004a). According to EPA's Safe Drinking Water Information System (SDWIS), the Kingston, Spring City, and Rockwood public water supply systems have not had any significant violations (USEPA 2004b). For EPA's monitoring schedules for each contaminant, go to http://www.epa.gov/safewater/pws/pdfs/qrg_smonitoringframework.pdf. On a quarterly basis, TDEC submits the individual water supply data to EPA's SDWIS (TDEC 2003c). To look up information and sampling results for public water supplies in Tennessee, go to EPA's Local Drinking Water Information Web site at <http://www.epa.gov/safewater/dwinfo/tn.htm>.

In addition, in 1996 TDEC's DOE Oversight Division began participation in EPA's Environmental Radiation Ambient Monitoring System (ERAMS). As part of the Oak Ridge ERAMS program, TDEC collects samples from five facilities on the ORR and in its vicinity. These public water suppliers include the Kingston Water Treatment Plant (TRM 568.4), DOE Water Treatment Plant at K-25 (CRM 14.5), West Knox Utility (CRM 36.6), DOE Water Treatment

EPA's ERAMS program was established to provide radiological monitoring for public water supplies located close to US nuclear facilities.

Plant at Y-12 (CRM 41.6), and Anderson County Utility District (CRM 52.5) (TDEC 2003b). Under the Oak Ridge ERAMS, TDEC collects finished drinking water samples from the Kingston Water Treatment Plant on a quarterly basis and then submits the samples to EPA for radiological analyses. The schedule and contaminants sampled at the Kingston Water Treatment Plant are available at <http://www.state.tn.us/environment/doeco/pdf/EMP2006.pdf>. Also see the TDEC–DOE Oversight Division’s annual report to the public at <http://www.state.tn.us/environment/doeco/active.shtml> for a summary of radiological drinking water sampling results. TDEC has also conducted filter backwash sludge sampling at Spring City—radioactive contaminants from the reservation could potentially move downstream into community drinking water supplies. TDEC analyzed Spring City samples for gross alpha, gross beta, and gross gamma emissions (TDEC 2002, 2003a, 2003b). To ask specific questions related to your drinking water, contact TDEC’s Environmental Assistance Center in Knoxville, Tennessee at 865-594-6035. To find additional information related to your water supply or other water supplies in the area, please call EPA’s Safe Drinking Water Hotline at 800-426-4791 or visit EPA’s Safe Drinking Water Web site at <http://www.epa.gov/safewater>.

Watts Bar Reservoir and Clinch River Turtle Sampling Survey, May 1997. TDEC conducted this survey to assess the body burdens of contaminants in snapping turtles in the Clinch River and in the Watts Bar Reservoir. Because of PCB contamination, fish advisories had been in effect for several years, and TDEC was concerned that people who consumed turtles from these water sources could also be exposed to PCBs. TDEC concluded that PCBs and additional contaminants accumulate in turtles from the Clinch River and the Watts Bar Reservoir. Data from the area fish advisories show that the PCB concentrations in turtle tissue were detected at levels of concern for human consumption. The majority of PCB contamination was detected in the fat tissue of the turtles, which is also seen in fish. Thus food preparation techniques, particularly tissue selection, can significantly influence the quantities of PCBs consumed with turtle meat (ATSDR et al. 2000). A brief summary of this survey is in Appendix D.

II.F.4. DOE

Watts Bar Interagency Agreement, February 1991. DOE, EPA, TVA, TDEC, and USACE comprise the Watts Bar Reservoir Interagency Working Group (WBRIWG), which works collaboratively through the Watts Bar Interagency Agreement—an agreement that established

guidelines related to any dredging in Watts Bar Reservoir. Through this agreement, these agencies review permitting and all other activities that could possibly disturb the sediment of Watts Bar Reservoir, such as erecting a pier or building a dock (ATSDR 1996; Jacobs EM Team 1997b; USDOE 2003a). The agreement also establishes guidelines for reviewing potential sediment-disturbing activities in the Clinch River below Melton Hill Dam, including Poplar Creek (Jacobs EM Team 1997b). According to the interagency agreement, DOE is required to take action if an institutional control is ineffective or if a sediment-disturbing activity could cause harm (USDOE 2003a).

Permit coordination under the Watts Bar Interagency Agreement was established to allow TVA, USACE, and TDEC (the agencies with permit authority over actions taken in Watts Bar Reservoir) to discuss proposed sediment-disturbing activities with DOE and EPA before conducting the normal permit review process to determine if there are any DOE contaminants in the sediments. The coordination follows a series of defined processes as outlined in the agreement.

The basic process of obtaining a permit, which is detailed in Section III.B.3, is the same for any organization or individual. If dredging is necessary in an area with contaminated sediments, DOE will assume the financial and waste management responsibility that is over and above the costs that would normally be incurred (Jacobs EM Team 1997b). For more details, please see the Clinch River/Poplar Creek OU ROD at <http://www.epa.gov/superfund/sites/rods/fulltext/r0497075.pdf> and page 3–5 of the Lower Watts Bar Reservoir ROD at <http://www.epa.gov/superfund/sites/rods/fulltext/r0495249.pdf> (Jacobs EM Team 1997b; USDOE 1995a).

Oak Ridge Environmental Information System (OREIS), April 1999. Because an abundance of environmental data exists for the ORR, DOE created an electronic data management system to integrate all of the data into a single database. This database was developed to facilitate public and governmental access to environmental data related to ORR operations, while also maintaining data quality. DOE's objective was to ensure that the database had long-term retention of the environmental data and useful methods to access the information. OREIS contains data related to compliance, environmental restoration, and surveillance activities.

Information from all key surveillance activities and environmental monitoring efforts is entered into OREIS. These include but are not limited to studies of the Clinch River embayment and the Lower Watts Bar Reservoir, as well as annual site summary reports. As new studies are completed, the environmental data are entered as well (ATSDR et al. 2000).

Comprehensive Epidemiologic Data Resource (CEDR). CEDR is a public-use database that contains information pertinent to health-related studies performed at the Oak Ridge Reservation and at other DOE sites. DOE provides this easily accessible, public-use repository of data (without personal identifiers) collected during occupational and environmental health studies of workers at DOE facilities and nearby community residents. This large resource organizes the electronic files of data and documentation collected during these studies and makes them accessible on the Internet at <http://cedr.lbl.gov>. Most of CEDR's large data collection pertains to about 50 epidemiologic studies of workers at various DOE sites. Of particular interest to Tennessee residents is an additional feature of CEDR (at <http://cedr.lbl.gov/DR/ordr.html>) that provides searchable text for about 1,800 original government documents (now declassified) used by the TDOH scientists for the Oak Ridge Dose Reconstruction. Also available through CEDR at <http://cedr.lbl.gov> are all of the technical and summary reports produced by this study. For the first time, this complex information is easily accessible in a concise, uncluttered, and easily comprehended manner. In addition, CEDR now provides images in slideshow format that give estimated concentrations, doses, and risk values for three contaminants (iodine, mercury, and uranium) in air at locations studied in TDOH's Dose Reconstruction.

III. Evaluation of Environmental Contamination and Potential Exposure Pathways

III.A. Introduction

In 2001, ATSDR scientists conducted a review and analysis of the Phase I and Phase II screening evaluation of TDOH's Oak Ridge Health Studies to identify contaminants that require further public health evaluation. In the Phase I and Phase II screening evaluation, TDOH conducted extensive reviews of available information and conducted qualitative and quantitative analyses of past (1944–1990) releases and off-site exposures to hazardous substances from the entire ORR. Having reviewed and analyzed Phase I and Phase II screening evaluations, ATSDR scientists determined that past releases of uranium, mercury, iodine 131, fluorides, radionuclides from White Oak Creek, and PCBs require further public health evaluation. The public health assessment is the primary public health process ATSDR is using to evaluate these contaminants further.

ATSDR scientists previously prepared a public health assessment on uranium releases from Y-12 and addressed current public health issues related to the East Fork Poplar Creek and the Lower Watts Bar Reservoir (LWBR). ATSDR is conducting public health assessments on the following releases: Y-12 mercury releases, X-10 iodine 131 releases, K-25 uranium and fluoride releases, and PCB releases from X-10, Y-12, and K-25. Public health assessments will also be conducted on other issues of concern, such as the Toxic Substances Control Act (TSCA) incinerator and off-site groundwater. In addition, ATSDR is screening current (1990 to 2003) environmental data to identify any other chemicals that will require further evaluation.

This public health assessment focuses on exposures to X-10 radionuclide releases to the Clinch River and the Lower Watts Bar Reservoir via White Oak Creek. More specifically, it evaluates 1) the data and findings of previous studies and investigations of X-10 radionuclide releases to the LWBR and the Clinch River via White Oak Creek; 2) assesses whether people who previously used the river, people who continue to use the river, or neighboring residents have been or could be exposed to radionuclides or radiation; and 3) determines the health implications of past, current, and future radiation exposure.

III.A.1. Exposure Evaluation Process

A release of a contaminant from a site does not always mean that the substance will have a negative impact on a member of the off-site community. For a substance to pose a potential health problem, exposure must first occur. Human exposure to a substance depends on whether a person comes in contact with the contaminant, for example by breathing, eating, drinking, or touching a substance containing it. If no one comes into contact with a contaminant, then no exposure occurs—and thus no health effects can occur. Even if the site is inaccessible to the public, contaminants can move through the environment to locations where people could come into contact with them. In the case of radiological contamination, exposure can occur without direct contact because of the emission of radiation, which is a form of energy.

The five elements of an exposure pathway are (1) source of contamination, (2) environmental media, (3) point of exposure, (4) route of human exposure, and (5) receptor population. The source of contamination is where the chemical or radioactive material was released. The environmental media (e.g., groundwater, soil, surface water, air) transport the contaminants. The point of exposure is where people come in contact with the contaminated media. The route of exposure (e.g., ingestion, inhalation, dermal contact) is how the contaminant enters the body. The people actually exposed are the receptor population.

ATSDR evaluates site conditions to determine if people could have been or could be exposed to site-related contaminants. When evaluating exposure pathways, ATSDR identifies whether exposure to contaminated media (soil, water, air, waste, or biota) has occurred, is occurring, or will occur through ingestion, dermal (skin) contact, or inhalation. ATSDR also identifies an exposure pathway as *completed* or *potential*, or *eliminates the pathway from further evaluation*. Completed exposure pathways exist if all elements of a human exposure are present. (See “Exposure Pathway” in Appendix A for a description of the elements of a completed exposure pathway.) A potential pathway is one that ATSDR cannot rule out because one or more of the pathway elements cannot be definitely proved or disproved. A pathway is eliminated if one or more of the elements are definitely absent.

Identifying the Types of Radiation Exposure

There are two broad classes of radiation exposure: internal radiation and external radiation. Internal exposures result from radioactive sources taken into the body through the inhalation of radioactive particles or the ingestion of contaminated food. External exposure results from

radiation sources originating outside the body, such as radiation emitted from contaminated sediment. These external sources can sometimes penetrate the human skin. Whether an exposure contributed to an individual's internal or external exposure depends primarily on the type of radiation—that is, alpha and beta particles or gamma rays—to which a person was exposed. Most radionuclides associated with White Oak Creek releases are beta or gamma emitters. Through its scientific evaluation, ATSDR eliminated internal radiation exposure from alpha particles associated with X-10 releases as a concern (see the text box).

Beta particles can penetrate human skin and tissues and deliver a dose both internally and externally.

Gamma rays can travel long distances and easily penetrate body tissues, and are therefore the primary type of radiation that results in external radiation exposures. Most radionuclides from X-10 were beta or gamma emitters.

Alpha particles cannot penetrate skin, so they pose a minimal external exposure concern. Alpha particles can inflict biological damage if the body takes them in, for example by breathing or swallowing radioactive material in air or food. However, alpha particles were not associated with the majority of radionuclides released to White Oak Creek.

Source: ATSDR 1999b

Deriving Radiation Doses

ATSDR scientists calculate the radiation dose by using the concentration of the radionuclide in

The radiation dose is the amount of energy from radiation that is actually absorbed by the body.

the environment and, if available, site-specific exposure factors such as time spent outdoors and amount of water ingested. If these site-specific factors are unavailable,

ATSDR either uses default values or derives region-specific values. Once these inputs are derived, the dose coefficient that converts the radiation concentration to the radiation dose is applied. ATSDR scientists might use worst-case exposure factors as the basis for determining whether adverse health effects are *possible*. Because of this approach, the estimated radiation doses are usually much higher—that is, more conservative—than the levels to which the majority of people are exposed. Note that the concept of radiation dose is not as simple as related here; a number of other factors (for example, how radionuclides decay, the critical organ concept, particle size distribution, and the chemical form) might affect “dose” and therefore need to be factored into the dose derivation.

ATSDR uses the term “conservative” to refer to values that are protective of public health in essentially all situations. Values that are overestimated are considered to be conservative.

Internal radiation exposure from a radionuclide continues after the initial radioactive material has been taken into the body, even if no additional radionuclides are ingested or inhaled. That is, internal exposure of radiation from radioactive material commits the exposed person to receiving a radiation dose for a period of time that typically depends on the radionuclide's half-life and rate of elimination from the body. (See *III.A.2.a.* for a discussion on half-life.) This dose is called the *committed equivalent dose* for an organ-specific dose and the *committed effective dose* for a whole-body dose. Exposure to external radiation sources, however, stops when the source is removed or when a person moves away from the source. A dose associated with external radiation is called an *effective dose*. The doses are further defined as follows:

Committed Equivalent Dose

The International Commission of Radiological Protection's (ICRP's) term (starting with ICRP Publication 60) for the dose to organs and tissues of reference that an individual will receive from an intake of radioactive material over a 50-year period following the intake for workers or adults and over a 70-year period following the intake for children.

Committed Effective Dose

ICRP's term for the sum of the products of 1) the weighting factors applicable to each body organ or tissue that is irradiated and 2) the committed equivalent dose to the appropriate organ or tissue integrated over time (in years) following the intake, with the assumption that the entire dose is delivered in the first year following the intake. The integrated time for an adult is 50 years; for children, it is from the time of intake to 70 years. The committed effective dose is used in radiation safety because it implicitly includes the relative carcinogenic sensitivity of the various tissues.

Effective Dose

ICRP's term (starting with ICRP Publication 60) for the sum of the products of 1) the weighting factors applicable to each body organ or tissue that is irradiated and 2) the mean equivalent dose in the tissue or organ following exposure to external radiation.

The organ dose (equivalent, H_T) and the whole-body dose (effective, E) can be defined mathematically using the equations below. W and D are the weighting factor and dose, respectively. The subscripts R and T represent the type of radiation and the tissue of concern.

$$H_T = \sum_R W_R D_{R,T} \text{ (organ, equivalent dose)}$$

$$E = \sum_T W_T H_T \text{ (whole body, effective dose)}$$

The sum of the equivalent dose is theoretically equal to the effective dose (E). By rearranging the equations, one can solve for the equivalent dose from the whole-body (effective) dose:

$$H_T = \frac{E}{\sum_T W_T}$$

Weighting factors (W_T) are modifying factors selected for the type of radiation and its energy as it impacts matter to convert organ or tissue dose equivalents to committed effective dose equivalents for the whole body. They are used because the same radiation exposure to different parts of the body can have very different results. That is, if the entire body were irradiated, some parts of the body would react more dramatically than other parts. To take this effect into account, the ICRP developed weighting factors for a number of organs and tissues that most significantly contribute to the overall biological damage to the body (ICRP 1991).

The tissue weighting factors are based on both cancer fatality risk and the relative effect of an exposure to a single organ or tissue.⁶ The grouping of tissues is complex, and substantial rounding of the values takes place. When summed for the entire body, the values of W_T are normalized to give a total of one. Table 6 gives the currently adopted tissue weighting factors.

Table 6. Tissue Weighting Factors

<i>Tissue</i>	w_T	$\sum w_T$
Bone marrow (red), colon, lung, and stomach	0.12	0.48
Bladder, breast, esophagus, liver, and thyroid	0.05	0.25
Bone surface and skin	0.01	0.02
Gonads	0.20	0.20
Remainder tissues—adrenals, brain, intestinal tract, kidneys, muscle, pancreas, spleen, thymus, and uterus	0.05	0.05
Total		1.0

⁶ For 2005, the ICRP is proposing a new system, which still involves weighting factors, that uses cancer incidence and considers lethality rate, years of life lost, and weighted contribution from the nonfatal cancers and hereditary disorders.

Assessing Health Effects

In its public health assessments, ATSDR uses radiation doses *instead of risk* to evaluate potential human exposures and health effects. ATSDR defines **dose** as “The amount of a substance to which a person may be exposed, usually on a daily basis.” Dose is often explained as the “amount of substances(s) per body weight per day” and is the basis for determining levels of exposure that might cause adverse health effects. The Society for Risk Analysis defines **risk** as

“The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred” (SRA 2004).

EPA-conducted risk assessments are useful in determining safe regulatory limits and in prioritizing sites for cleanup. These risk assessments provide estimates of theoretical risk from possible current or future exposures and consider all contaminated media—regardless of whether exposures are occurring or are likely to occur. That said, however, these quantitative risk estimates are not intended to predict the incidence of disease or to measure the actual health effects in people resulting from site-related hazardous substances. By design, these risk estimates are conservative predictions that generally overestimate risk. Risk assessments do not provide a perspective on what the risk estimates mean in the context of the site community, nor do they measure the actual health effects that hazardous substances have on people. Please see Appendix F for more information on risk.

ATSDR recognizes that every radiation dose, action, or activity may carry an associated risk. ATSDR uses the public health assessment process to evaluate the public health implications of exposure to environmental contamination and to identify the appropriate public health actions for particular communities. A public health assessment provides conclusions about the actual existence and level of the health threat (if any) posed by a site, as well as recommendations to stop or reduce exposures. Because of uncertainties regarding exposure conditions and adverse effects related to environmental levels of exposure, definitive answers on whether health effects actually will or will not occur are not possible. A public health assessment can, however, provide a framework that puts site-specific exposures and the potential for harm in perspective. Thus, ATSDR recognizes that uncertainties exist with doses, but it addresses these uncertainties by using health-protective safety factors.

Exposure does not always result in harmful health effects. The type and severity of health effects a person can experience depend on the dose, which is based on age at exposure, the exposure rate (how much), the frequency or duration of exposure (how long), the route or pathway of exposure (breathing, eating, drinking, or skin contact), and the multiplicity of exposure (combination of contaminants). Once a person is exposed, characteristics such as age, gender, nutritional status, genetics, lifestyle, and health status influence how that person absorbs, distributes, metabolizes, and excretes the contaminant. The likelihood that adverse health outcomes will actually occur depends on site-specific conditions, individual lifestyle, and genetic factors that affect the route, magnitude, and duration of actual exposure—an environmental concentration alone will not cause an adverse health outcome.

As a first step in evaluating radiation exposures, ATSDR health assessors screened the radiation doses against comparison values. ATSDR develops comparison values from available scientific literature concerning exposure, dose, and health

ATSDR uses comparison values to identify hazardous substances that are not considered a health hazard at a site and hazardous substances that require an additional follow-up evaluation.

effects. Comparison values represent radiation doses that are lower than levels at which no effects were observed in studies on experimental animals or in human epidemiologic studies. They are not thresholds for harmful health effects; instead, they reflect an estimated dose that is not expected to cause harmful health effects. Estimated doses below these comparison values are not considered a health hazard, so doses at or below the relevant comparison value can reasonably be considered safe. Doses above the comparison values, meanwhile, will not necessarily produce adverse health effects. This screening process enables ATSDR to safely eliminate contaminants that are not of health concern and to evaluate potentially harmful contaminants further.

If the estimated radiation doses at a site are above comparison values, ATSDR proceeds with a more in-depth health effects evaluation to determine if the doses are sufficient enough to trigger public health action to limit, eliminate, or further study any potential harmful exposures. ATSDR scientists conduct a health effects evaluation by carefully examining site-specific exposure conditions about actual or likely exposures; conducting a critical review of radiologic, medical, and epidemiologic information in the scientific literature to ascertain the levels of significant human exposure; and comparing an estimate of the radiation doses that people might frequently

encounter at a site to situations that have been associated with disease and injury. This health effects evaluation involves a balanced review and integration of site-related environmental data, site-specific exposure factors, and toxicologic, radiologic, epidemiologic, medical, and health outcome data to help determine whether exposure to contaminant levels might result in harmful effects. The goal of the health effects evaluation is to decide whether harmful effects might be observed in the exposed population by weighing the scientific evidence and keeping site-specific doses in perspective. See Figure 19 for ATSDR's health-based determination of radiological doses.

More information about the ATSDR evaluation process can be found in ATSDR's Public Health Assessment Guidance Manual at <http://www.atsdr.cdc.gov/HAC/PHAManual/toc.html> or by contacting ATSDR at 1-888-42-ATSDR. An interactive program that provides an overview of the process ATSDR uses to evaluate whether people will be harmed by hazardous materials is available at <http://www.atsdr.cdc.gov/training/public-health-assessment-overview/html/index.html>.

III.A.2. Radiation-Related Terms

Half-Life

The half-life of a radionuclide is the time that it takes for the activity of radioactive material (or radioactivity) to decrease by one-half. This is known as the physical half-life. Radionuclides that are taken into the body will also be eliminated by biological processes, such as excretion. The measure of time it takes to eliminate half of a material taken into the body by biological processes is called the biological half-life. The measure of the combined influences of these physical and biological half-lives is called the effective half-life. For example, as shown in Table 7, the physical half-life of strontium 90 is about 10,439 days and the biological half-life is about 18,000 days for bone. Therefore, the effective half-life of strontium 90 deposited in the bone is 6,400 days. That is, half the radioactivity of strontium 90 taken into the body will be gone after 6,400 days, another half of the remaining radioactivity will be depleted after an additional 6,400 days, and this process will continue as the radioactivity is depleted from the body. The effective half-life is always less than or equal to either its physical or biological half-life.

Figure 19. ATSDR Health-Based Determination of Radiological Doses

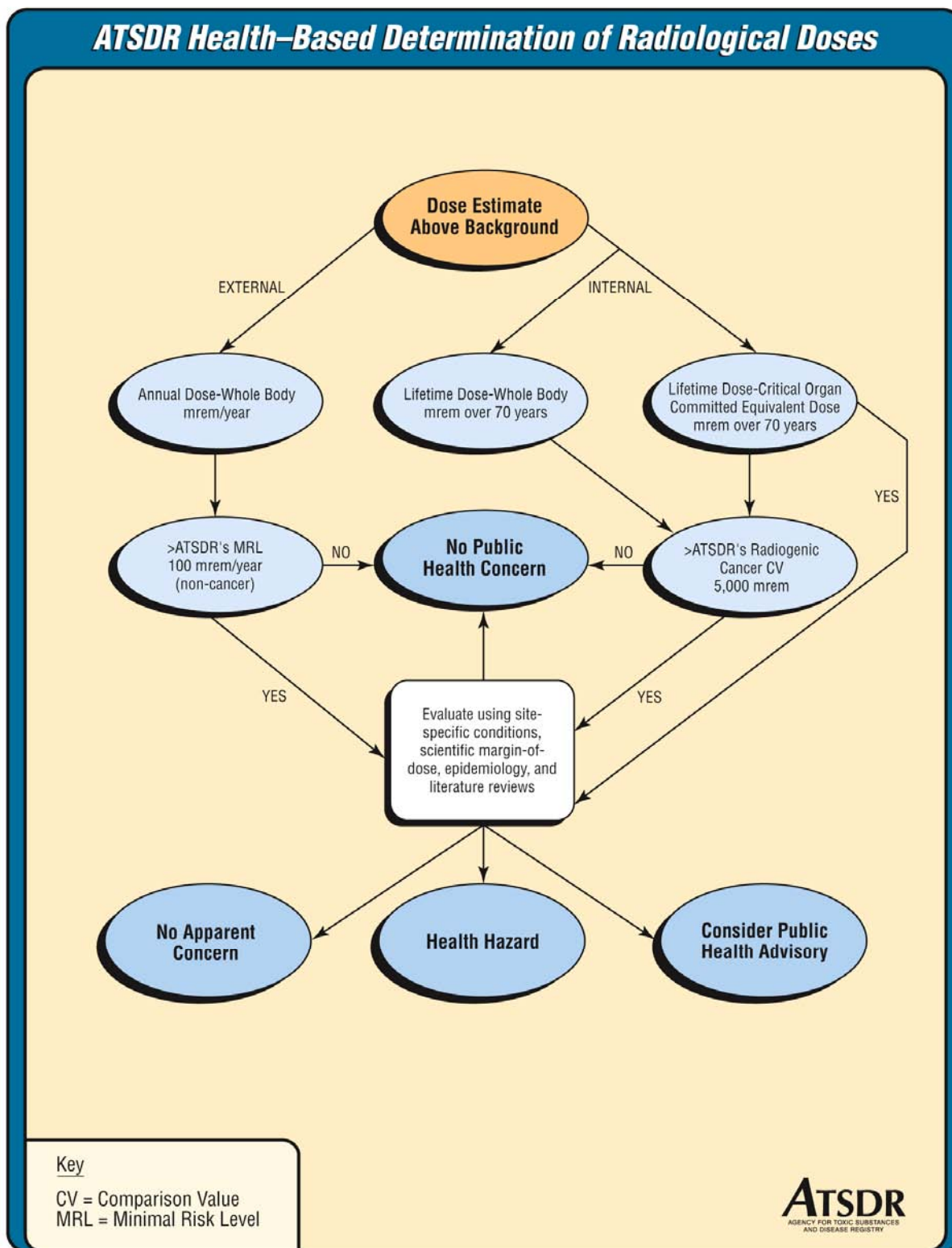


Table 7. Half-Lives (in days) of Selected Radionuclides in the WOC PHA

<i>Radionuclide</i>	<i>Physical Half-Life</i>	<i>Biological Half-Life</i>	<i>Effective Half-Life*</i>
Tritium	4,490	12 (whole body)	12 (whole body)
Cesium 137	11,023	70 (whole body)	70 (whole body)
Strontium 90	10,439	18,000 (bone)	6,400 (bone)
Cobalt 60	1,935	9.5 (whole body)	9.5 (whole body)
Yttrium 90	2.7	14,000 (bone)	2.7

* Effective half-life is the time required for the radioactivity of a radionuclide to be diminished 50 percent through the combined action of radioactive physical decay and biological elimination.

Radiological Measurements

This PHA uses two systems for radiological measurements and doses: the Conventional System and the Systeme International. The key in Table 8 describes these units and lists their abbreviations.

Table 8. Units for Radiological Measurements

<i>System</i>	<i>Unit</i>	<i>Parameter/Description</i>
Conventional System	picocurie, pCi	The curie (Ci) is the basic unit of radioactivity. The pCi is 1,000,000,000,000 (one trillion) times smaller than one Ci.
	millirem, mrem	Dose is given in units "roentgen equivalent man" or rem. One mrem is 1,000 times smaller than one rem. This is the unit for both the equivalent dose and the effective dose.
Systeme International	becquerel, Bq	The basic unit of activity is the becquerel (Bq). The number of curies must be multiplied by 3.7×10^{10} to obtain an equivalent number of Bq.
	millisievert, mSv	The sievert (Sv) is the unit of equivalent dose and the effective dose. One mSv is 1,000 times smaller than one Sv. The number of millisieverts (mSv) must be multiplied by 100 to convert to millirem.